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MINIMIZING AND ANALYZING CONSTRUCTION
DELAY AND ITS IMPACTS:

Case Studies and Knowledge-Based Systems

A Special Research Problem

Presented to

The Faculty of the School of Civil Engineering
Georgia Institute of Technology

THESIS
B458175

by

Steven G. Bertolaccini

In Partial Fulfillment
of the Requirements for the Degree of
Master of Science in the School of Civil Engineering
May 1989

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF CIVIL ENGINEERING
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Abstract

This report will examine the fundamental principles associated with construction delay and recovering from that delay through actual acceleration. Methods for minimizing or elimimating construction delay and analyzing its impact on cost, quality, and timely completion of construction projects will be presented. A prototype expert system will be developed to assist the public and private owner in minimizing the possibility of construction delay. Additionally, two methods of schedule compression will be examined. A case study of the acceleration which occurred during construction of the Air Force One Maintenance and Support complex will be presented.

Acknowledgements

I would like to thank the United States Navy for allowing me the opportunity to pursue an education beyond the baccalaureate level. I would also like to recognize the faculty at Georgia Tech, in particular the efforts of Dr. Paul Sanders and Dr. Leland Riggs, for accommodating the rigorous time constraints and providing the opportunity for me to obtain a Master of Science in Civil Engineering.

I gratefully acknowledge the support and guidance provided by LT Bob Raines, CEC, USN, and my advisor Dr. Roozbeh Kangari. Their contributions to this project were immense.

I would like to thank my parents for their continued love and support and my wife who was the model of support, patience, and understanding throughout my postgraduate studies.

Finally, I thank God for providing me with the ability and perseverance to complete this project. This work is dedicated to Him.

SGB

CHAPTER 1

Introduction

In business and finance, it is said that "time is money", but at least most people are wise enough not to say that "money is time", because they eventually realize that time is priceless.

- Kieth Collier, 1982

1.1 Introduction

The impact of delay upon a construction project can be devastating and seldom is a project completed without having suffered some type of delay. The owner is in the best position to allocate the construction risks and thereby significantly reduce the probability of delay. If the construction owner understands the causes of delay and how to effectively manage delay, he can take the appropriate actions to avoid or minimize its impact. Even though an owner may take all the proper precautions, some delays are inevitable. Accordingly, the need for analyzing the time and cost impact on a delayed project and accelerating a project to recover from delay, is not diminished.

1.2 State of the Art

The ability to minimize, analyze, and recover from construction delay is extremely important to all parties in the construction process. Several recently published books and papers deal extensively with the issues of

analyzing the impacts of delay on project time and cost and presentation of claims for recovery of delay losses. In 1987, Albert Phillips, John Stetson, and Barry Bramble presented an excellent article on Construction Disputes and Time at the first Annual Construction Law and Practice Potpourrie. It describes in detail analyzing, documenting, and quantifying delay damages and methods of presentation for proving delay damages. Expert Systems are also being applied to the field of construction delay. In 1987, the U. S. Army Construction Engineering Research Laboratory sponsored a workshop on Expert Systems for Construction Scheduling. Expert Systems for automated network generation, measurement, and analysis were discussed [O'Connor et al,1987].

1.3 Objective and Scope

The primary focus of this paper is to illustrate the fundamentals required for (1) minimzing the possibility of delay prior to the award of design and construction contracts, (2) analyzing the impact of delays which occur during construction, and (3) accelerating the project to recover from that delay. This report is not intended to be a comprehensive study of every impact of delay and acceleration on a construction project. Rather, it attempts to provide a basic understanding of the fundamental concepts that are required for successful management of delay.

1.4 Methodology

In Chapter Two the fundamentals crucial to understanding and managing construction delays are presented. Delay is defined, categorized, and its causes and effects are closely scrutinized. Chapter Three presents the major risks which must be considered prior to award of design and construction contracts and ways to manage these risks to reduce or eliminate the possiblity of delay. In Chapter Four an expert system developed for use

by the owner is presented. This expert system will aid the owner in determining the most probable cause of delay on his project and provide reccomendations to avoid or minimize that delay. Chapter Five discusses the fundamental issues involved in time impact analysis studies. Impact costs associated with delay are presented and a case study is provide in Appendix II. Chapter Six discusses the cost impacts of project acceleration and presents two methods for compressing a construction schedule. A case study of acceleration implemented during constuction of the new Air Force One support and maintenance complex is presented in Chapter Seven.

CHAPTER 2
Fundamentals of Delay

2.1 Introduction

Construction delay is simply the time required beyond the contract completion date to fulfill the terms of the contract. The extension of time is normally due to unforseen circumstances which arise during execution of the contract. In general any delay will adversely effect both the contractor and the owner.

2.2 Recovery of Damages

The contractor's means of recovery are limited to negotiation, mediation, arbitration and litigation. Negotiation is the cheapest and consequently the most preferred method. However, both sides must be willing to compromise. In many circumstances a mutually satisfying solution can not be achieved. Mediation and arbitration are also viable options which are gaining popularity because of the decreased costs and time involved in dispute settlement. Unfortunately , many disputes are still resolved by litigation, the most costly and time consuming process available. To begin the litigation process the contractor must file a delay claim. According to Lambert and White [Lambert et al,82],

> *"A delay claim is essentially a claim that the contract has been breached, and it is an elementary principle of contract law that a breach must be material- in other words, important to the value of the contract in the eyes of the other party."*

Phillips, Stetson and Bramble [Phillips et al,88] wrote that in order for the contractor to recover from a delay the following must be demonstrated:

(1) The contractor must have been delayed for a specific period of time..

(2) The contractor had no responsibility for any part of the delay.

(3) The owner or representative of the owner was responsible for the delay.

(4) The contractor incurred an additional expense that would have not been incurred otherwise.

(5) The amount of the expense is known.

If the contractor can adequately support these criteria, the litigation will most likely be successful.

The owner has all of these tools at his disposal along with one other- Liquidated Damages. Liquidated damages are an attempt by the owner to quantify as best possible, any damages that may be incurred as a result of delay. Liquidated damages are applied at a per diem rate. These damages may include easily quantifiable damages such as lost rent or other damages, not so readily quantifed, such as loss of production or visibility. The owner can not recover any more or less for a project delay. However, this does not prevent the owner from recovering damages due to any other breach of contract.

Frequently, the contractor views liquidated damages as a penalty imposed by the owner. This is simply not the case. If liquidated damages were a penalty they would be unenforceable by the courts. To ensure enforceability, liquidated damages must be a reasonable attempt to measure

any forseeable damages and be based on actual damages that are difficult to quantify.

If a liquidated damages clause is not included in the contract the owner may collect actual damages. However, these damages must have been forseeable at the time the contract was awarded. The contractor knows the intended use of the facility and therefore can be held responsible for any damages pertaining to the delayed turnover of the facility [Jervis, 88].

2.3 Types of Delay

There are three basic types of delay. They are: excusable, compensable, and non-excusable. These delays can stand alone, act concurrently or cause delay in follow on activities. It is extremely important to understand the differences between each type of delay and in what manner they affect the project.

2.3.1 Excusable Delay

An excusable delay is one for which neither the owner nor the contractor is responsible. The list provided below includes the most common causes of excusable delay but is not intended to be comprehensive [O'Brien,76].

1. Acts of God
2. Acts of public enemy
3. Acts of the government
4. Acts of another contractor in performance of a Government contract
5. Fires
6. Floods
7. Epidemics
8. Quarantine Restrictions
9. Strikes
10. Freight embargos

11. Unusually severe weather
12. Delays of subcontractor or suppliers due to similar circumstances

The three required elements of any excusable delay are that it be unavoidable, uncontrollable, and unforeseeable. Therefore, the items listed above are not always causes of excusable delay. For example, if a contractor knew a labor strike was imminent or on going when the project was bid the delay would not be unforeseen and therefore not a cause for excusable delay. Additionally, if either the contractor or the owner were involved in labor negotiations and intentionally lengthened the strike to delay the project the delay would not be unavoidable or uncontrollable or a cause for excusable delay.

Unusually severe weather merits further discussion. The contractor must include in his bid price the costs of delay due to the anticipated weather conditions for the geographic location and the contract performance time frame. The estimate should be based on historical weather data for the local area. Only weather conditions which exceed historical norms are justifiable causes of excusable delay. For example, if the average number of days of rainfall for the month of November is eight and the actual number of rain days was eight or less, the contractor could not claim rain as cause of an excusable delay for November. Conversely, if the rainfall exceeded eight days in November the contractor could claim the days exceeding eight as a valid cause of excusable delay. The contractor must also show that the project was indeed delayed by the number of days claimed. Obviously, rain would not be a likely cause of delay for interior construction.

In circumstances where excusable delay exists it is customary to allow the contractor a time extension equivalent to the allowable delay but provide no monetary compensation. Both the contractor and the owner must

absorb their own delay costs and the contractor is relieved of his obligation to pay liquidated damages for the number of days of excused delay . Neither party is responsible for an unforeseeable and uncontrollable delay. Accordingly, neither party should gain an advantage because of an excusable delay.

2.3.2 Compensable Delays

A compensable delay is one for which the owner, designer or one of the owner's agents is completely responsible. The list below is a summary of the major causes of compensable delays but is not all inclusive[O'Brien, 76, Bramble, Callahan 87].

Owner Caused

1. Failure to provide access property or right of way
2. Failure to fund the project
3. Owner furnished materials not available
4. Suspension of work
5. Introduction of major changes
6. Disruption of work
7. Failure to make progress payments
8. Interference by other prime contractors working for the owner

Designer or CM Caused

1. Defects or ommissions in plans or specifications
2. Unreasonable delay in reviewing and approving shop drawings and submittals
3. Improper or delayed change orders
4. Orders to stop work
5. Direction to accomplish work in a certain manner
6. Failure to coordinate between prime contractors
7. Inadequate subsurface investigation
8. Inadequate supervision
9. Delays in inspection and testing

If the owner, designer or agent of the owner delay or disrupt the contractor in any manner the owner must compensate the contractor any

additional costs and time. However, the contractor must proceed diligently with work and minimize the impact of the delay as much as possible.

2.3.3 Non-Excusable Delay

Responsibility for non-excusable delay rests solely with the contractor. The following is a list of the most common causes of non-excusable delay [O'Brien,76]:

1. Slow to mobilize
2. Failure to provide necessary manpower
3. Failure to supply sufficient material
4. Failure to provide adequate equipment
5. Poor quality control
6. Poor project supervision and management
7. Poor coordination between sub-contractors
8. Unforeseen accidents
9. Poor project planning
10. Bid Shopping
11. Cash flow problems

It is important to note that most contracts include a clause which states that the prime contractor is responsible for the action or inaction of the subcontractors. Therefore, if a subcontractor or supplier fail to deliver material, labor or equipment on time the prime contractor would be held completely responsible for the delay.

In the event of a non-excusable delay the contractor receives no compensation for time or money. In which case the contractor would be subject to liquidated or actual damages and any acceleration costs incurred bringing the project back on schedule.

2.4 Single, Serial, and Concurrent Delay

Once the responsibilty for the delay has been established, the delay must be analyzed in the context of the entire project. The time frame,

number and length of the delays need to be considered. Accordingly, the manner in which delays impact the project can be classified as either single, serial or concurrent.

2.4.1 Single Delay

A single delay is delay in its simplest form. No other delay acts concurrently with a single delay and its impact can be readily be determined. For example, a three month project is to be undertaken with a start date of 1 June and a completion date of 31 August and there are no other delays on the project. During the month of July the contractor lost eight work days due to rain. Historical weather data shows that the contractor could expect to lose only three work days due to rain during July. It was with this information that the contractor prepared his bid. All parties agree that the contractor is entitled to five additional work days because of the unusual number of rain days encountered. Assuming these rain days impacted critical path activities, the contract completion date would be extended five days to compensate for the lost time. Although the start date of some activities subsequent to the delayed activities would be impacted, their durations remain unchanged. Accordingly, the impact of this single delay extends the contract completion date but does not cause any further delay.

2.4.2 Serial Delay

Serial delay exists when the occurence of one delay is the cause of another delay. For example, suppose a contract is scheduled for completion in November. A two month labor strike deemed unforseeable and uncontrollable occurs during the month of September and October. Normally the contractor would be entitled to a two month time extension and a new contract completion date in January. However, the contractor will be unable

to work during the months of December, January and February due to the nature of the work and the severe weather conditions. The delay due to the strike has pushed the construction into the winter months and caused a subsequent or "serial" delay. In this case the contractor would recieve an additional time extension of three months to cover the time lost during the winter months.

2.4.3 Concurrent Delay

If two or more delays occur simultaneously, the delays are said to be "concurrent". It is considerably more difficult to resolve concurrent delays than single or serial delays and sometimes it is impossible. There are several permutations of concurrent delays all of which are discussed below. Simple examples are presented. Many additional factors may need to be considered. These will be discussed in more detail in Chapter 5.

2.4.3.1 Concurrent Delay with One or More Non-excusable Delays

If any delay concurrent with another delay is termed non-excusable, the time period during which the delays are concurrent is considered a non-excusable delay. The argument is that if the concurrent delay did not occur the contractor still could not have performed the work within the original time allowed by the contract. Accordingly, the contractor will receive no time or money for any concurrent delay period in which one or both of the delays are non-excusable. For example, a designer is late in returning approved shop drawings to the contractor causing a thirty day delay in the start of a project. However, the contractor is unable to obtain essential equipment in time and as a result would have to start the job twenty days late. Consequently, the first twenty days of the delay are non-excusable and the contractor would not receive compensation of any kind. The last ten

days of the delay are compensable and the contractor would receive time and money.

2.4.3.2 Concurrent Compensable Delays

The contractor receives compensation from concurrent delays only if all the concurrent delays are compensable. Again, the argument is that if the delay caused by the owner or one of his agents did not occur the contractor would still not have been able to perform the work because of contractor caused delay or an uncontrollable delay. To illustrate concurrent compensable delay consider the following : A contractor is delayed fifteen days while awaiting resolution of a design ambiguity. During this same period there is a five day labor strike and ten days of delay due to non-receipt of owner furnished material. The contractor would receive time but no compensation for the five days during which the labor strike occurred. However, during the remaining ten days all the delays occurring are compensable therefore entitling the contractor to both time and money.

2.4.3.3 Concurrent Excusable Delay

If two or more concurrent delays are excusable the contractor is entitled to an extension of the contract completion date in the amount of the largest excusable delay. For example, if the project is delayed by a ten day excusable delay acting concurrently with a fifteen day excusable delay the contractor is entitled to a fifteen day time extension.

2.4.3.4 Concurrent Excusable and Compensable Delay

The contractor is entitled to only a time extension if an excusable delay is concurrent with a compensable delay. Again, the prevailing argument is that the contractor would have been delayed whether the owner caused delay occurred or not. An example of concurrent excusable compensable delay would be if the contractor sustained a delay of twenty

days due to unusual weather while a concurrent fifteen day delay due to denial of site access occurred. In this case the contractor would be entitled to a twenty day time extension but no compensation.

2.5 Effects of Delay

There are many serious consequences of delay. It is important to understand the possible effects of delay so that if delay occurs the problems can be anticipated and planned for.

2.5.1 Costs

Time related costs increase in direct proportion to the length of the delay. The longer the delay the greater the increase in cost. Cost items such as home office overhead, field office overhead, on-site supervision, interest on loans and the decreased value of property are always important considerations in any delay. Depending on the length of the delay, labor, material and equipment costs are also important factors which may have to be considered. Cost will be considered in greater detail in Chapter 5.

2.5.2 Project Acceleration

Acceleration is very often the result of a delay in the construction process. The two basic types of acceleration are constructive and actual. Actual acceleration occurs when the owner acknowledges that an excusable or compensable delay has occurred and is willing to pay the contractor to accelerate his production rate to make up for lost time. Actual acceleration also occurs when the contractor has fallen behind schedule due to his own shortcomings and elects to accelerate the schedule to avoid liquidated damages or termination. Constructive acceleration occurs when the owner fails to recognize a legitimate delay and threatens the contractor with liquidated damages or termination forcing him to accelerate the schedule and finish on time.

2.5.3 Schedule Changes

Delays can be extremely disruptive to a project schedule forcing project managers to re-sequence activities. For example, a six man barracks was being constructed on the island of Bermuda by the Seabees. The structure consisted of construction masonry unit (CMU) walls on a concrete foundation with a wood truss roof. Several delays were encountered on the project but the most disruptive was the late arrival of the wood trusses. The trusses were scheduled for installation following erection of the CMU walls. However, because of their late arrival, the walls were stuccoed, sidewalks placed, and utilities installed all prior to the arrival of the trusses. The rescheduling of activities was a nightmare for the project manager, a demotivator for the crew, and forced an unorthodox and disruptive construction schedule upon the Seabees.

2.5.4 Crew Production and Efficiency Losses

There are several ways in which delays due to stoppage of work, rework, or rescheduling of work will adversely effect production and the efficiency of a construction crew. One of the most important effects is upon the learning curve. If work is interrupted, even for a relatively short period of time, the routine acquiring process of the crew may be disrupted and part of it could be lost [Gates,72]. For extended delays it is possible that original crew members will be lost. Consequently, new crew members will be brought on board and some measure of time will be required for the crew to attain its previous efficiency. Acceleration will also impact crew efficiency because of overcrowding at the jobsite and the effects of overtime on workers.

2.5.5 Prevention of Early Completion

If the contractor is ahead of schedule and encounters a delay, he is prevented from completing the project at the earliest possible date. Because of the delay the contractor sustains additional time related costs that would not otherwise have been incurred. It is important to note that the contractor could obtain compensation from the owner if the delay is compensable or time if the delay is excusable.

2.5.6 Abandonment of Project or Contract Termination

In the event of severe or prolonged delays the impact on the project may be much more significant. If the owner is unable to fulfill his financial obligations by making progress payments, the contractor may choose to abandon the job and place a lien against the property and/or work-in-place. The contract may be terminated by the owner if construction is substantially delayed by the contractor. Depending on the contract language, the owner may then bring in another contractor to complete the work at the expense of the original contractor.

CHAPTER 3

Minimizing or Avoiding the Consequences of Delay

3.1 Introduction

To minimize the consequences of delay it is crucial to understand the risks involved and to clearly indicate responsibility for those risks in the contract documents. Understanding the risks includes identifying, analyzing, and planning for them so that they may be reduced or avoided. One of the most important ways to minimize construction risks is to transfer the risks through the contract documents to the party best able to control them.

All constuction risks can basically be divided into five major categories:

1. *Physical risks*
2. *Economic risks*
3. *Political or Public risks*
4. *Contractual and Legal risks*
5. *Construction Related Risks*

Each category will be further subdivided and each risk element will be briefly discussed. The risk elements presented are not intended to be all inclusive, but to be representative of major risks found in todays construction industry. Much of the information introduced in this chapter can be found in great detail in a two volume publication of papers presented

at a "Construction Risk and Liability Sharing" conference sponsored by the American Society of Civil Engineers [ASCE,79].

3.2 Physical risks

Physical risks are very difficult to control or eliminate. The two major elements of physical risks include acts of God and unknown subsurface conditions.

3.2.1 Acts of God

Acts of God are obviously uncontrollable and include such events as fires, floods, unusually severe weather, etc.. Neither the contractor nor the owner is responsible for these risks. Therefore the owner and the contractor should share the risk. The owner should grant the contractor a reasonable time extension for the amount of delay incurred. Contractors normally carry insurance to cover losses caused by acts of God. If not , the owner should provide the insurance or require the contractor to obtain insurance prior to the start of the project. It is important that the risk be clearly stated in the contract documents regardless of which approach the owner selects. If the contract documents are not clear in this area the contractor will figure a contingency into his bid price to cover this risk. This may result in the owner paying for a contingency that will never occur.

3.2.2 Subsurface Risks

Differing site conditions are a major concern in evaluating construction risk because it is extremely difficult to precisely determine subsurface conditions. Accordingly, this risk is controllable only to a very limited extent. The owner needs to spend adequate time and money obtaining a reputable firm that will provide an accurate and extensive pre-bid survey of existing site conditions. Attempting to cut corners on subsurface exploration can lead to expensive and disasterous results [Sowers,79]. All

information discovered during the survey should be included in the contract plans and specifications in order to decrease contingency costs in the contractors bids. This pertains not only to factual information but also to any possible trends noted by the Geotechnical Engineer. Additionally, the bid documents should require that the contractor visit the site to enhance his knowledge of the site conditions. An extensive pre-bid survey will decrease the number of unknowns thereby reducing contingency costs in bids and the possibility of claims and change orders.

3.3 Economic Risk

There are several economic risks which must be considered when preparing contract documents. The major risks are inflation, the financial stability of all parties, the national and international economic trends and cash flow stability.

3.3.1 Inflation

Inflation is an uncontrollable risk that should be shared by both the contractor and the owner. By sharing the risks the owner and contractor can help mitigate the effects of inflation. Typically for project durations of eighteen months or greater, it is crucial to address inflation in the specifications. It is recommended that the specifications include base price, labor index, material index, ratio for division of costs between labor and material and provisions for changes in indices [Riggs,79]. The ratio for division of costs is normally 75% for the owner and 25% for the contractor. Inflationary risks should be the financial responsibility of the owner but the contractor is assigned some risk to ensure that he minimizes the cost effects of inflation on materials and keeps his bargaining position with the unions strong [Ribakoff,79]. Other ways the owner can reduce the effects of inflation is to reduce retainage, pay for mobilization and pay for materials

delivered to the job site. It is important that adjustments only be made for significant increases or decreases in inflation with "significant" being defined in the contract specifications.

3.3.2 Financial Stability of the Project and the Contracting Parties

This risk is somewhat controllable. The owner should be able to readily assess his own financial stability including all marketplace risks associated with the product or service he intends to provide. A project should not be undertaken without a strong commitment to see it through to completion. The owner can remove some of the financial risk by prequalifying the firms with whom he contracts and eliminating those that are not financially stable. The effects of contracting with a financially unstable contractor or designer can be devastating. Additionally, the owner should set aside funds to cover any contingencies which may arise. If all available funds are expended awarding the contract and no funds are available to cover changes, completing the project will be difficult at best.

3.3.3 National and International Economic Impacts

This is an uncontrollable risk which must be borne completely by the owner. There are many different ways in which national and international events can effect construction projects including embargoes, strikes, dollar devaluation and interest rate fluctuation. No one can accurately predict these events. Accordingly, owners should not expect contractors to do so. If provisions for the owner to assume these risks are not included in the contract, the contractor will increase his bid price and the owner will be paying for a contingency which may or may not occur. Interest rate fluctuations should not be accounted for unless there is a significant increase or decrease in the rate. Again, the term significant should be defined in the contract documents.

3.3.4 Prompt Payment

One of the most critical elements in avoiding delay and maintaining a good contractor/owner relationship is to ensure that the contractor is paid in a timely manner for work completed. Contractors normally require loans to buy material, rent equipment and pay workers. An unfair disruption in his cash flow would not only create an adversial relationship but quite possibly introduce delays into the project. It is extremely important that progress payments, change order payments and claim payments be prompt. The owner should place specific provisions in the contract documents relating to prompt payment to avoid contingencies in the bid price.

3.4 Political or Public Risks

Political or public risks are almost exclusively the financial responsibility of the owner whether he has any control over them or not. Risks involving environmental concerns, permits and ordinances, traffic maintenance, public disorder, tax rate changes, and governmental acts and regulations all must be considered prior to letting a contract.

3.4.1 Environmental Risks

As regulations for air, water, land, and noise pollution continue to tighten, it is increasingly important for an owner to contract with a competent and experienced design firm. A full account of the environmental impact of the project and all pertinent environmental regulations is essential prior to any contract award. Without thorough investigation, delay, financial loss and tarnished public image could result.

3.4.2 Permits, Ordinances, and Regulations

Another major concern for the owner is knowledge of the local ordinances and any applicable governmental laws or regulations. Zoning laws and local building codes can be extremely important risk factors which

must always be considered. Additionally, all required permits and pertinent safety regulations should be clearly identified in the contract. A competent designer, familiar with local regulations, is essential. Many designers are not familiar with codes outside their immediate area. This is an extremely important consideration when selecting a designer.

3.4.3. Traffic Maintenance

Responsibility for this risk rests only partially with the owner. Any disruption of traffic along public roads should be identified in the plans and specifications. Details to minimize disruptions should be discussed and resolved with the local public works and transportation department. The contractor should be responsible for coordination of the actual dates and physical arrangements. The contractor's responsibilities should be precisely outlined in the contract documents to avoid contingencies. Clearly, prequalifying the contractor and designer would help minimize the risk of delay.

3.4.4 Public Disorder

This is essentially an uncontrollable risk and the finanacial responsibility should be completely borne by the owner. Included in the risk is work stoppage due to international conflicts, riots, or demonstrations. Riots or demonstrations, if due to public opposition to the project, may be somewhat controllable if handled early and expeditiously. The owner should state in the contract documents that he will assume this risk.

3.4.5 Tax Rate Changes

A provision for the adjustment of contract price due to a specified increase or decrease in the tax rate should be included in the specifications. This will fairly compensate the contractor or the owner if there is a

substantial increase or decrease in the tax rates. Without this provision the owner will pay for a contingency regardless of any tax rate change.

3.5 Contractual and Legal Risks

Contractual and legal risks are much more easily controllable than other types of risks. With selection of the appropriate designer, contractor, and contract type, the risk of construction delay can be greatly reduced.

3.5.1 Selecting a Designer

In previous discussions the prequalifications or selection of a competent designer was mentioned frequently. Selection of an architectural and engineering firm may be the most important decision the owner must make. It is for this reason that the federal government negotiates contracts with designers rather than utilizing the lowest, responsible, responsive bidder approach used in most of their construction contracts. This promotes a more professional atmosphere and minimizes the risk of getting a poor design. The owner should provide sufficient time for project design and insist upon a thorough design review. Because of the propensity for errors and omissions, fast-track projects should be avoided whenever possible. If a project must be fast-tracked, then a turn-key contract should be considered.

Important factors which must be considered when selecting a designer include previous experience in this type of construction, firm size, familiarity with local area, references, claims experience, construction administration services, current workload, professional liability insurance, and personnel assigned to the design team.

3.5.2 Selecting a Contractor

The traditional method of selecting a contractor has been the low bidder approach. Unfortunately, this forces some contractors to cut corners to get the bid and seek to recover profit through change orders while

providing the owner with a product of minimum quality. The best means of eliminating the undesirable contractors is through prequalification. The contractor desiring to bid on the project should be examined for responsibility by using previous experience with this type of construction, current workload, size, bonding capacity, and references as guidelines. Prequalification will probably result in the bid price increasing but the chances of obtaining a poor contractor and the subsequent delay costs should be significantly reduced.

3.5.3 Selection of Contract Type

Selecting the proper contract is the key mechanism for transferring risk to the party best able to control it. The basic types of contracts available to the owner are fixed price and cost reimbursable. Fixed price contracts are attractive to the owner because they place most of the risk on the contractor. Cost reimbursable contracts on the other hand place most of the risk on the owner.

Fixed price contracts are used with standard designs which are complete prior to bidding and require no special equipment or material. Cost reimbursable contracts are appropriate only if a fixed price contract cannot be used. It is used most often for incomplete designs, performance specifications, fast-track projects, or if excessive uncertainties are involved with the project. The primary advantage of most cost reimbursable contracts is that the contractor is rewarded for reducing costs, which creates an atmosphere where the contractor and the owner are working together to reduce costs. However, these contracts require good documentation and can be a heavy administrative burden. In the absence of significant change orders or claims, the price of a cost reimbursable contract could be

sustantially higher. Table 3.1 shows some of the risk implications of different contract types.

3.5.3.1 Firm Fixed Price

In a firm fixed price contract the contract price is fixed and is not subject to any variation except those indicated in the contract documents. To utilize this type of contract a significant amount of time is required. A full set of plans and specifications must be developed and ample time provided for review of bids and award of a contract. Owners prefer this type of contract because it places the maximum amount of risk on the contractor. However, this forces the contractor to include contingencies in his bid price and increases the cost of the project. The owner can greatly reduce contingencies in bid prices by insuring that the plans and specifications are complete and accurate with no ambiguities. The rigidness of the firm fixed price contract makes claims and change orders more prevalent particularly on contracts awarded to the lowest bidder. The administrative burden of a firm fixed price contract is much less than that of other contracts provided the amount of contract changes and claims are small. Additionally, because the contractor wants to maximize profit the quality of the project will be minimized. One variation of the firm fixed priced contract worth mentioning is unit pricing. Unit pricing is utilized when exact quantities are not known. The contractor submits his unit price bid for an estimated quantity and is payed in accordance with the actual quantity. An example of where unit pricing might be appropriate is for a project requiring a large excavation and the quantity of rock to be excavated can only be estimated. The contract would include a seperate unit price bid item for rock removal. The contractor would provide a price per cubic yard based on the estimated quantity. The unit price would vary only if the quantity of rock excavated

TABLE 3.1 Risk Implications of Different Types of Contracts [Hayes et al,86]

Characteristic	Lump sum	Unit price	Target Cost	Cost reimbursable
Financial objectives of client and contractor	Different but reasonably independent	Different and in potential conflict	Considerable harmony. Reduction of actual cost is a common objective if cost remains in the incentive region	Both based on actual cost but potentially in conflict
Flexibility for design change, variations	Very limited	Some	Extensive	Unlimited
Evaluation of change by client	Little or no information available from tender	Mainly based on tendered prices and rates	Target adjustment based on actual costs and utilisation of resources or target rates available	Unnecessary for contractual purposes. Actual costs paid
Design/ Construction overlap early start to construction	Impracticable	Feasible but relatively limited	Considerable opportunity	Construction may be started when first design package is available
Contractor's involvement in design of permanent works	Excluded	Usually excluded	Contractor encouraged to contribute ideas for reducing actual cost	Contractor may be appointed for design input prior to construction
Client involvement in construction management	Excluded	Retrospective	Recommended through joint planning	Should be active
Payment for risks	Undisclosed contingency in contractor's tender	Undisclosed contingency in contractor's tender plus claims	Payment of actual cost of dealing with risk only if it occurs Target adjusted accordingly	Payment of actual cost
Claims resolution	Very difficult - no basis for evaluation	Difficult - client has no knowledge of actual cost or hidden contingency	Potentially easy - based on actual costs or target costs Mechanism needs careful draughting	Unnecessary except for fee adjustment - usually relatively easy
Knowledge of final price at tender (excluding inflation)	Known	Uncertain - tender price usually increased by variations and claims	Uncertain - tender target cost usually increased by variations but effective joint management and efficient working can reduce final payment to below target cost	Unknown

varies beyond a certain tolerance, typically 15 percent. Since the contractor has spread his fixed costs over the entire estimated quantity, if the quantity of rock removed is less than estimated, the cost of removing each cubic yard of rock has increased. Conversely, if the quantity increases, the cost will decrease and the owner is entitled to a reduction in price (not withstanding escalation of direct costs). Unit pricing offers many of the advantages of fixed price contracts with only a minimal increase in administrative overhead. It also provides the flexibility for dealing with specific items of work whose quantities are unknown.

3.5.3.2 Fixed Price with Escalation

The fixed price with escalation contract provides adjustments in the contract price for items specifically defined in the contract. It is commonly used in contracts of long duration where increases in labor, material, and equipment costs are probable. It may also be used where a particular market may be unstable. The contract can specifically outline a course of action based on a specific occurrence in the marketplace. This type of contract will increase the administrative burden and transfer some of the risk to the owner, but will reduce bid contingencies.

3.5.3.3 Fixed Price Incentive Firm

The fixed price incentive firm contract allows for the adjustment of profit based on the closeness of the target and total costs. This type of contract is used when sufficient detail for firm fixed price bidding is not available without excessive provisions for contingencies, but enough detail is available to develope a target cost [Ribakoff,79]. There are four main components to this type of contract:

1. Target cost

2. Target profit

3. Ceiling price

4. Sharing formula

The target cost is the base cost to which the final cost is compared. The target profit is received if the project comes in at the target cost. If the final cost is below the target cost the contractor receives a percentage of the savings based upon a negotiated percentage included in the sharing formula. Hence, the profit potential is unlimited. If the cost of the project exceeds the target cost by a specified amount the profit will begin decreasing until the ceiling price is reached. At this point profit is zero and the contractor will have to absorb any further costs as a loss. This type of contract provides the contractor with an incentive to cut costs but the contractor must have an excellent cost accounting system to track costs. In addition to the increased administrative burden, negotiating the target cost, target profit, ceiling price and sharing formula can be tedious.

3.5.3.4 Cost Plus Incentive Fee

In the cost plus incentive fee contract, the target cost, target fee, minimum and maximum fees, and fee adjustment formula are negotiated prior to award. The contractor profit is reduced if the target cost is exceeded and increases if a savings is realized based upon the negotiated fee formula. This type of contract is utilized where insufficient detail in the plans and specifications prohibits use of a fixed price contract. It is particularly applicable for fast-track or complex projects. However, it is imperative that both the owner and contractor have competent organizations and a solid working relationship. In addition to the disadvantages mentioned in the

fixed price incentive firm contracts, the final contract price is not limited. However, by accepting more of the risk, the owner will reduce the amount of contingencies in the contract price and subsequently avoid paying for contingencies which may not occur. It also provides the contractor with greater motivation to reduce project costs.

3.5.3.5 Cost Plus Award Fee

In the cost plus award fee contract, the contractor is paid for all costs incurred on the project and a predetermined amount of profit. Additionally, the contractor can earn an award fee from the owner based on meeting specific criteria in areas such as quality of construction, reduction of costs, and achievement of project milestones [Ribakoff,79]. The award is determined solely by the owner and is not subject to appeal by the contractor. This method will produce a better working relationship between the contractor and owner because both are trying to accomplish the same goals. Also, the contractor is provided a great incentive to complete the work at the lowest cost and highest quality in the shortest time frame. The disadvantages are those common to all cost reimbursement type contracts with some additions. If there is a conflict in personalities the award fee may be unjustly reduced. Additionally, because the total cost is usually a key factor in determining the award, it may be very difficult for the parties to agree on a final cost.

3.5.3.6 Cost Plus Fixed Fee

In the cost plus fixed fee type contract, the contractor is paid a fixed fee irregardless of the total cost of the project. Its principle application would be in emergency situations or where the owner and contractor have worked together previously and have a significant degree of trust for one another. Its one main advantage over the previously mentioned cost

reimbursement contracts is that many of the potential areas of disagreement with respect to fees and awards are removed. The additional disadvantages with the cost plus fixed fee are that the contractor does not have an incentive to cut costs and an accurate cost estimate is required prior to contract award. Without a good cost estimate, the negotiated fee may not be appropriate.

3.5.3.7 Cost Plus Percentage of Cost

As the name implies, the contractor's profit is awarded as a percentage of the total contract. The federal government prohibits the use of this type of contract because the contractor is motivated to increase project costs because they are tied directly to his profit. These types of contracts are most applicable to emergency situations where it is imperative that the contract be completed in the shortest possible time or where the contractor and the owner have a long and outstanding relationship. The owner's risk is greatest in this type of contract.

3.5.4 Insurance

In most situations the cost for insurance is minimized if the contractor carries his own insurance. It is also more fitting since it is the contractor who is responsible for and has the most control over safety at the jobsite. Wrap-up insurance should be considered for any "super" project "in which a number of diverse interests with differing levels of liabilities and different levels of financial capabilities are involved" [Hammond,79]. This will ensure that the project is properly covered by insurance. In any event, the insurance bearer must be clearly delineated in the contract documents.

3.5.5 Resolution of Disputes

If disputes arise on a project, they must be resolved expeditiously. There are several ways in which to accomplish this. Of singular importance

is establishing a good working relationship early in the project. A trusting and cooperative atmosphere can only be built through good communication at all levels. Regular meetings are extremely helpful in keeping all parties informed on the current issues. During negotiations, utilizing tactics and strategies or holding a trump card will only prolong discussions [Bramble, Callahan,87]. Compromising early will avoid the unnecessary losses of time and money often accompanying lengthy disputes. Additionally, thorough documentation is a prerequisite to resolving any dispute quickly. Without documentation, it is extremely difficult to resolve any dispute. Finally, the time frame and procedures utilized in resolving disputes should be clearly identified in the contract.

3.5.6 Contract Clauses and Terms

There are many contract clauses and terms which play a vital role in properly allocating risk and consequently lessen the opportunity for additional costs and delay.

3.5.6.1 Liquidated Damages Clause

The inclusion of a liquidated damages clause in construction contracts not only provides the owner with recovery of losses due to a delayed completion but also provides the contractor with an incentive to finish on time. If the stipulated damages are unreasonably high the contractor will increase the contingency cost in his bid to protect himself. Additionally, if the liquidated damages are proven to be unreasonably high the courts will only force the contractor to pay actual damages [Jarvis,88].

3.5.6.2 Contract Duration

It is essential that the owner provide sufficient time for the contractor to complete the project. If the contract duration is too short, the contractor will be required to perform the the work in an "accelerated" manner. This

additional cost will be passed along to the owner. Furthermore, the contractor's risk of being assessed liquidated damages will increase and consequently so will his bid price.

The owner must also ensure that the contract duration not be too long. For example, several years ago a construction firm received a contract from the government to renovate an interior office. The contract was awarded for a twelve month duration yet the actual construction time was only two months. The shrewd contractor gutted the office in the first month and did not return to work until the final month of the contract. Obviously, the dislocated occupants and the governments' construction managers were displeased but the contractor was within his rights to schedule the work as he pleased. However, the ploy was unsuccessful as the government chose to live with their mistake and would not pay to have the contractor accelerate his schedule.

3.5.6.3 Exculpatory Clauses

Most exculpatory or disclaimer clauses serve only as an attempt to pass responsibility from its rightful owner to the contractor. Designers are the most frequent abusers as they often include these clauses to protect themselves from design errors and omissions. These clauses increase the contingencies in a contractors bid and if taken to court are usually held invalid. Consequently, the owner pays twice for the same mistake. Exculpatory clauses may be effective in very specific terms, but are extremely ineffective in general terms. The best choice is to simply eliminate them entirely.

3.5.6.4 Differing Site Conditions

The differing site conditions clause is a standard part of any federal government or American Institute of Architects contract. These clauses

allow the contractor to recover from any unforeseen differences in the site conditons provided he gives the owner timely notice of the changed condition. Most of these are due to the subsurface risks discussed in section 3.2.2. This risk rightfully belongs to the owner and inclusion of the clause advises the contractor that the owner will accept the risk. Accordingly, the contractor will not include a contingency for the possibility of differing site conditions in his bid.

3.5.6.5 Changes Clause

Most contracts include a changes clause which allows the owner to request changes in the work as long as the change is within the general scope of the contract. This clause gives the owner the flexibility to make minor in-scope changes to the work to meet any additional needs. It also lets the contractor know that he will be compensated for any additional time or cost involved.

3.5.3.6 Time Extension - Termination

The time extension-termination clause should define the conditions under which the contractor is allowed an extension of time to complete the contract requirements or be prevented from further performance on a contract. If the delay is compensable or excusable the contractor should be allowed a time extension without fear of liquidated damages or termination. The clause should also clearly state the conditions under which a contractor will be terminated. Failure to prosecute work in a diligent manner (non-excusable delay) is the primary consideration. The purpose of this clause is to fairly allocate the risk of delay to the party best able to control it.

3.6 Construction Related Risks

Construction related risks include those risks directly related to jobsite progress but not applicable to any other risk category.

3.6.1 Delayed Site Access

Obviously this is a risk which should be borne entirely by the owner. Prior to contract award the owner must ensure that the site will be accessible or stipulate in the contract the date that the site will be available. The contractor has the right to begin construction immediately upon completion of any administrative requirements specified in the contract. If he is unable to mobilize and has the right to mobilize, he may rightly claim delay.

3.6.2 Poor Management

It is essential for the owner to have a good project management system. If he does not have the experience or technical expertise in house, he should strongly consider hiring a construction management firm. An independent firm with experience and expertise should be able to quickly and fairly resolve disputes. Competent firms will be able to save time and money by expediting paper work and spotting potential areas of conflict. They will also be able to develop a comprehensive risk and liability management plan for the project.

The most important aspect of managing a project is good communication. It is imperative that whoever manages the project have exceptional communications skills. Good project management promotes productivity and supports quality construction completed in a timely manner at the lowest cost.

3.6.3 Quality Control

Detailed clauses for quality control and quality control inspectors that are firm but fair will go a long way towards achieving a quality project. The clauses should stipulate submission of catalog cuts on important materials, necessary shop drawings, and a quality control plan. The inspectors cannot

be too lax in their duties or quality may slip. If over zealous, they could easily create an adversarial relationship with the contractor that will continue throughout the project. Inspection is a very difficult job and it is important to select an exceptional person to properly perform those duties .

3.6.4 Material Constraints

Owners should severely limit the material constraints they place on the contractor. Some owners believe they save overhead and profit by purchasing the material themselves. However, the contractor can usually obtain materials at a better price because he deals with local vendors on a regular basis. The owner is also taking the risk of delaying the contractor if the materials do not arrive in time. If the owner has selected a special material which is not readily available, late arrival and project delays should be anticipated. Accordingly, the owner should avoid special materials whenever possible and allow the contactor to purchase the bulk of the material himself.

CHAPTER 4

AN EXPERT SYSTEM FOR DELAY

4.1 Introduction

The best strategy to avoid or minimize delay is to address the possible areas of delay prior to design and contract award. Obviously the owner is in the best position to make this determination, however, he very often does not have the required expertise. Accordingly, this prototype expert system was developed to help the public or private owner in recognizing the most probable delay likely to occur on a particular project. The program will also provide recommendations to minimize or avoid the possibility of delay. Many of the principles and concepts discussed in Chapters One and Two were utilized in developing this program.

4.2 Background on Expert Systems

For the past three decades computer experts have been attempting to develop programs which could solve problems in a manner that could be considered intelligent. The program could examine the process it followed to arrive at its conslusion and learn from any mistakes it made. This is the field of artificial intelligence.

During the 1960's researchers were initally examining general problem solving methods and attempting to use them to create general purpose programs. These attempts were relatively unsuccessful. Therefore, in the early 1970's the researchers tried to improve the formulation of the problems to make them easier to solve and control the search such that the solution could be obtained as quickly as possible. Some success was

acheived, but it was not until the late 1970's when researchers discovered that in order "to make a program intelligent provide it with lots of high-quality specific knowledge about some problem area" [Waterman,86]. This was the beginning of expert systems and the next step towards the development of artificial intelligence.

An expert system is basically a computer program with a high level of expert knowledge in a particular domain which can be used to solve problems in that domain. The primary difference between knowledge based systems and conventional computer systems is that conventional systems will go through myriads of calculations to produce an exact answer while knowledge based systems use a heuristic approach to solve problems which may not have an exact answer. They instead will provide an acceptable solution most of the time. Table 4.1 and figure 4.1 outline many of the differences between the two. Additionally, expert systems have several advantages and disadvantages when compared with the capabilities of humans. These are shown in tables 4.2 and 4.3.

4.3 Developing Expert Systems

Expert systems can be developed to perform many different functions including predictive modeling, training, high-level expertise and institutional memory [Waterman,86]. The most important link in the development of an expert system is the domain expert. Paul E. Johnson, a scientist who has studied the behavior of human experts for many years offers the following description of an expert:

> *"An expert is a person who, because of training and experience is able to do things the rest of us cannot: experts are not only proficient but also smooth and efficient in the actions they take. Experts know a great many things and have tricks and caveats for applying what they know to problems and tasks; they are*

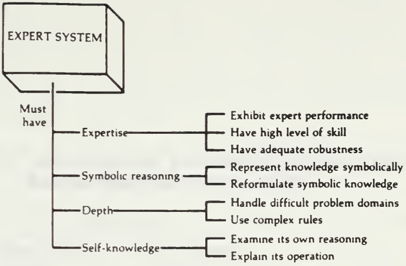


FIGURE 4.1 Expert System Characteristics [Waterman,86]

TABLE 4.1 Comparison of Data Processing and Knowledge Engineering [Waterman,86]

Data Processing	*Knowledge Engineering*
Representations and use of data	Representation and use of knowledge
Algorithmic	Heuristic
Repetitive process	Inferential process
Effective manipulation of large data bases	Effective manipulation of large knowledge bases

TABLE 4.2 Advantages of Artificial Expertise versus Human Expertise [Waterman,86]

The Good News	
Human Expertise	*Artificial Expertise*
Perishable	Permanent
Difficult to transfer	Easy to transfer
Difficult to document	Easy to document
Unpredictable	Consistent
Expensive	Affordable

TABLE 4.3 Disadvantages of Artificial Expertise versus Human Expertise [Waterman,86]

The Bad News	
Human Expertise	*Artificial Expertise*
Creative	Uninspired
Adaptive	Needs to be told
Sensory experience	Symbolic input
Broad focus	Narrow focus
Commonsense knowledge	Technical knowledge

also good at plowing through irrelevant information in order to get at the basic issues, and they are good at recognizing the problems they face as instances or types with which they are familiar. Underlying the behavior of experts is the body of operative knowledge which we have termed expertise. It is reasonable to suppose, therefore, that experts are the ones to ask when we wish to represent the expertise that makes their behavior possible." [Johnson,83]

The expertise utilized in these systems are not limited to the experts alone. Expertise may also be obtained from books and articles as well.

With the knowledge obtained from the domain expert, the knowledge engineer should then utilize an appropriate tool to structure the best possible program. This entire process is illustrated in figure 4.2. The final product should be user friendly and allow the user to obtain the necessary information as quickly as possible.

The two primary steps in developing an expert system are acquiring the knowledge from the expert and formalizing the knowledge.

4.3.1 Acquisition of Knowledge

Before interviewing the domain expert it is imperative that all background research be complete. Discussions should focus on identifying the basis of knowledge, how the knowledge is represented and organized, and any imprecisions in the knowledge. After discussing the problems in complete detail, the knowledge engineer should go through each step in the process with the domain expert [Kangari,88]. Good communication between the knowledge engineer and the domain expert is essential for developing a good model.

4.3.1 Formalizing the Knowledge

After obtaining the knowledge, the key concepts and their relationships must be organized and classified in a formal manner. The program utilizes a production rule (IF-THEN-ELSE) format for presentation of

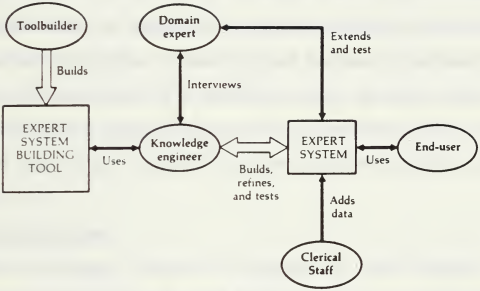


FIGURE 4.2 Expert System Development Process
[Waterman,86]

knowledge and definition of relationships. Also known as the inference engine, it is the mechanism which allows the user to move through the program to obtain a solution in the quickest possible manner. The program can also access data bases for knowledge or arithmatic programs for routine problem solving.

4.4 An Expert System for the Construction Owner

The intention of this program is to aid the owner in determining the most probable cause of delay for a particular project and provide a recommendation to minimize or possibly avoid the delay. Additionally, the owner may use this program as a checklist by which all areas of delay may be researched prior to design and award of a construction project. A hard copy of this program and a diskette have been included with this report as Appendix I.

4.4.1 The Domain Expert

The two primary sources of expertise for this program were Lieutenant Robert Raines of the Civil Engineer Corps of the United States Navy, and knowledge obtained through articles, books, papers and graduate studies in Construction Management at the Georgia Institute of Technology. Lt. Raines has a Masters Degree in Construction Management from Stanford University and has worked in the construction industry for 15 years, the last eleven years as a project manager for the federal government. He has negotiated millions of dollars in delay change orders and has been formally recognized by the Navy for his outstanding achievements in construction management. Several literary sources proved valuable in developing this program including "Construction Delay" by O'Brien [O'Brien,76], a doctoral thesis on "Risk Classification" presented by Erikson at the University of

Illinois [Erikson,79], and papers published from the "Construction Risks and Liability Sharing" conference [ASCE,79].

4.4.2 The Tool

"Insight 2+" was the tool utilized to develop the knowledge base and inference engine as well as provide a run-time environment for the program. "Insight 2+" will run on most IBM compatible systems and utilizes the MS DOS operating system. The system uses production rule language which can be developed from most word processing systems. DBASE II, dBASEIII, and DBPAS support is provided with "Inside 2+" as well as its own text editor. Other programs can be added to the package at the users discretion. Confidence factors can be utilized with every user input to help quantify the "trueness" of the responses. Figure 4.3 gives a basic overview of the system.

4.4.3 The Program

This program is intended for the owner or CM of a future project who has limited knowledge of the construction process. The program is user friendly and all statements proposed to the user can be expanded to provide additional information. It is intended to be used during the preconstruction phase; after a developer and site have been attained, but prior to the finalization of design and construction specifications. There are two primary paths by which the recommended actions to minimize or avoid delay may be obtained:

(1) The expert system will determine the area of most probable delay

(2) The user selects the area of delay to be minimized or eliminated.

This is the first input required of the user.

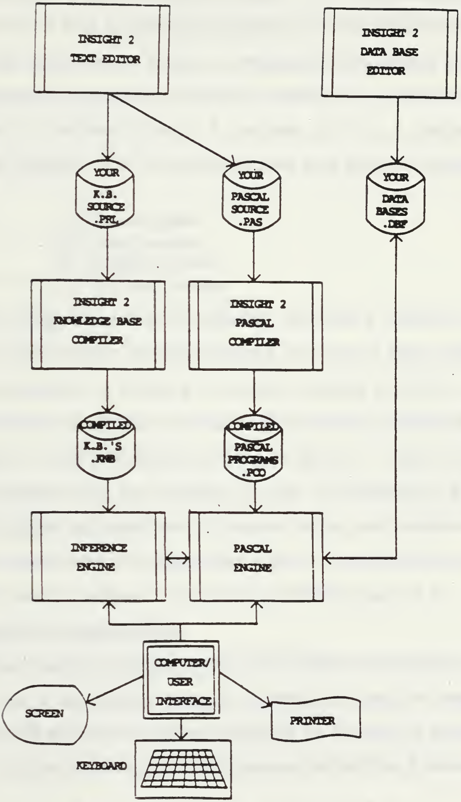


FIGURE 4.3 Insight 2+ System Overview
[Insight 2+ User's Manual]

4.4.3.1 Determination of the Most Probable Delay

After selecting this path, the user is first routed to a pool of 16 equally weighted questions which are listed in table 4.4. The statements are introduced one at a time and the user responds to each statement with his confidence that the statement is true. A response of 100 percent indicates that the statement is completely true while a response of 2 percent indicates the statement is completely false. A response of 0 or 1 percent will terminate the program. The 16 questions cover four general categories of delay:

(1) Uncontrollable
(2) Owner caused
(3) Designer caused
(4) Contractor caused

Each general category has four statements. The user's response to the statements in each category are then averaged. The area of delay which has the highest probability of occurring (or highest average) is selected. Once inside the specific area of delay, the user is given several statements about specific delays. These statements are given in table 4.5. Again, the user enters his confidence that the statement is true. The statement which is assigned the highest confidence level is selected as the most probable delay. The user is then provided with suggestions to avoid or minimize the possible effects of this delay. The logic of this path is provided in figure 4.4.

4.4.3.2 Selection of a Specific Delay

If the user selects this path, he must first choose the specific category of delay. Once in the specific category of delay, the user can select the specific delay and examine the recommendations for avoiding or minimizing the delay. If utilized in this manner, the program can serve as a resource for

TABLE 4.4 Statements to Determine the Most Probable General Cause of Delay

GENERAL STATEMENTS TO WHICH THE USER MUST RESPOND WITH HIS CONFIDENCE THAT THE GIVEN STATEMENT IS TRUE

1. There is a high probability of severe weather or natural disaster occurring.

2. This project is politically sensitive.

3. Labor forces available for the project will be limited due to either the possibility of a labor strike of future resource criticality.

4. This project requires specially manufactured material or materials for which the supply is limited.

5. You are not financially stable.

6. Your borrowing capacity is limited.

7. The market for your service or product is questionable and the project may be terminated prior to completion.

8. You will be highly involved in project operations and are likely to institute many change orders.

9. The designer is relatively new or is not experienced in this type of construction.

10. The current workload for the designer exceeds the workload capacity of the firm.

11. The designer has been forced to complete the plans and specifications in a shorter time frame than normally required or construction has started before the plans and specifications are 100 percent complete.

12. The design is extremely complex or unique.

13. The contractor is not experienced in this type of construction.

14. The contractor is not financially stable.

15. The contractor is not large enough to handle the project or has too large of a workload to perform all contracts satisfactorily.

16. The companys' management utilizes outdated management techniques or company has history of late completions, poor quality, or poor safety record.

TABLE 4.5 Statements to Determine the Most Probable Specific Cause of Delay

SPECIFIC STATEMENTS TO WHICH THE USER MUST RESPOND WITH HIS CONFIDENCE THAT THE GIVEN STATEMENT IS TRUE

Uncontrollable Delay

1. The geographic location has a high probability of severe weather, i.e.,tornadoes,etc..
2. Normal weather conditions are poor for the area.
3. The subcontractors on this job are unreliable.
4. There is a good possibility of a shortage of material.
5. There is local labor unrest, a short supply of skilled workers or union contract expires during job duration.
6. There is a likelihood of local opposition to the project.

Owner Caused Delay

1. Your Borrowing Capacity is in question.
2. You are a new or relatively small organization.
3. You typically become involved in daily construction operations or frequently change items in the plans and specifications after contract award.
4. You historically make late progress payments.
5. The project is very risky or depends on agencies outside the design/developement team.

Designer Caused Delay

1. The designer is not experienced in this type of construction.
2. The project involves experimental construction techniques.
3. Construction started prior to 100% completion of drawings and specifications.
4. The designer is slow in approving shop drawings and submittals.
5. The designer's staff is small or current job volume is large.
6. The designer is not familiar with local buildings or environmental regulations.

Contractor Caused Delay

1. The contractor is not experienced in this type of construction.
2. The contractor does not have sufficient borrowing or bonding capacity.
3. The contractor does not use modern management techniques.
4. The contractor does not have sufficient manpower to coordinate or supervise the project.
5. The contractors bid was significantly lower than you estimate.
6. Other projects completed by this contractor have poor records of safety, quality, or timely completion.

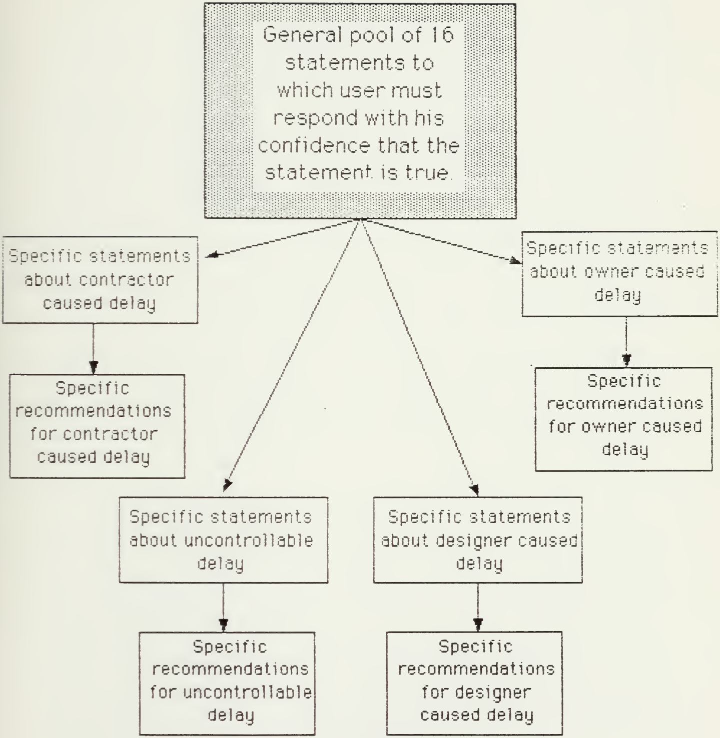


FIGURE 4.4 Path for Determining the Most Probable Delay

swiftly obtaining specific recommendations for avoiding or minimizing a specific delay. Figure 4.5 outlines the logic of this path.

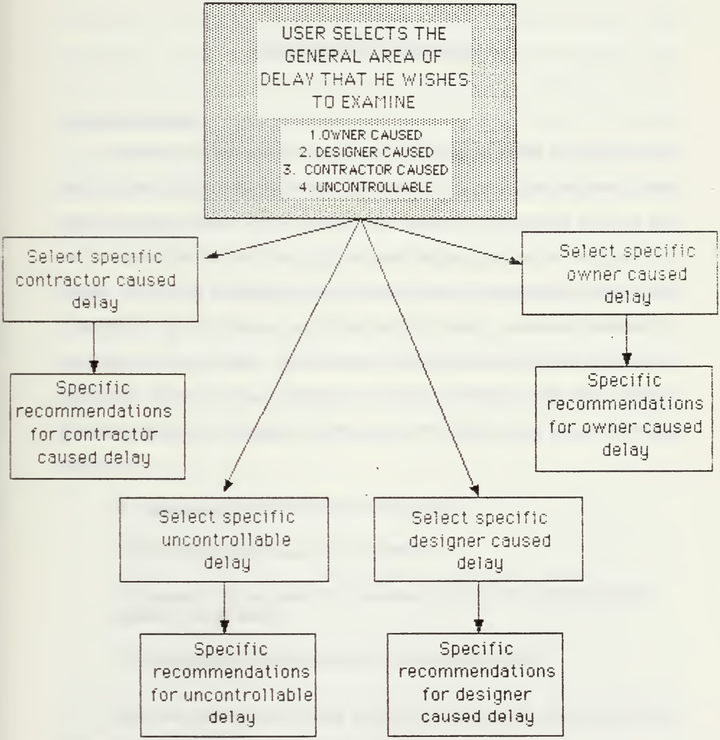


FIGURE 4.5 Path for Selecting a Specific Delay

CHAPTER 5

TIME IMPACT ANALYSIS

5.1 Introduction

Although all the proper steps may be taken to avoid or minimize the risk of delay, delays will still occur. Therefore, it is important to have a basic understanding of how delay impacts the project with respect to time and cost. Many different methods exist for conducting time impact analysis on a project. The Corps of Engineers uses a step by step process where each delay is anlayzed for its impact upon the project and a separate schedule is developed for each delay. The Veterans Administration includes the effects of all the delays on one schedule and then proceeds with the analysis. Whatever method is selected, there are a few basic steps that are always required:

(1) Examination of all pertinent documents

(2) Construction of an as-built schedule

(3) Compare the as-built to as-planned schedule and determine the impact of each delay

(4) Analyzing concurrent delays to determine liability

There are three basic criteria which must be met for the contractor to be granted relief from a delay claim [Lee,83]:

(1) Causation

(2) Liability

(3) Damages

Causation is simply identifying the delay and determining its impact upon the project through a time impact study. The liability for the delay must also be determined, i.e., is the delay compensable, excusable, or non-excusable. Finally, the damages incurred must be proven and may include extended overhead, escalation, loss of productivity, etc. The damages should not be determined until the cause of the delay and liability for the delay have been established.

Different types of scheduling techniques have been used for conducting a time impact analysis but the best is the Critical Path Method (CPM). CPM has an advantage over Bar Charts because it demonstrates the interrelationship between activities. The Bar Chart is popular because of its simplicity and ease of understanding, but as the General Services Board of Contract Appeals in Minmar Builders, Inc., GSBCA No.3430, 72-2 B.C.A (CCH) Para. 9599 (1972) stated:

> *"Since no interrelationship was shown between the tasks, the charts cannot show what project activities were dependent on the prior performance of the plaster and ceiling work, much less whether overall project completion was thereby affected. In short the schedules were not prepared by the critical path method(CPM) and hence are not probative as to whether any particular activity was on the critical path or determined the pacing element of the project." Id. at Para. 44,857.*

Several other cases have supported this same decision. Therefore, the use of CPM in determining the impact of a delay on a construction project would appear to be the best option.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

5.2 Gathering Information

Before an analysis of the project can begin, all project documents must be thoroughly examined. This includes the plans and specifications, the contract and its clauses, daily logs, quality control reports, invoices, letters, submittal logs, shop drawing logs, schedules, change orders, etc. The investigators should have great skill and experience in scheduling and time impact analysis to competently perform the investigation. The scheduling experts must get a thorough understanding of the contract before beginning the analysis. The documents must also be organized into a format which makes them readily accessible. The investigation involves examinimg a myriad of details and documents and determining which delays affected the project and which did not. Obviously, it is crucial to have good documentation. Without it, any claim will be difficult to support.

5.3 Creating the As-Built Schedule

After the documents have been examined and the expert has a good feel for the project, the as-built schedule must be constructed. This schedule must accurately reflect the actual schedule followed by the contractor. Project documents must confirm every aspect of the as-built schedule. If not, the claim may fall apart in court.

5.4 As-Planned Schedule

In order to obtain an accurate estimate of the impact of delays on a project a detailed as-planned schedule is required. Before construction begins the contractor is required in most contracts to submit a schedule of work for approval by the owner. The schedule is normally a detailed CPM diagram which depicts project milestones, activity durations, and interdependencies of activities. Many contracts require the contractor to submit an updated project schedule with all invoices. However, if any

schedule changes occur, the schedule should be updated reflecting those changes and the rationale behind them. The effect on the critical path should be checked to determine if it has shifted.

It should be noted that anytime the contractor incurs a delay the owner should be notified in writing. Many contracts contain clauses which state that the contractor must notify the owner of a change within a specified time period. If the owner is not notified he cannot respond to the delay and possibly mitigate its impact. In some instances the courts have disallowed claims because the owner was not notified in a timely manner.

5.5 Analyzing the Delay

The important dimensions of delay analysis are [Bramble et al,87]:

(1) Excusability
(2) Compensability
(3) Concurrency
(4) Criticality

The contractor is entitled to a time extension if the delay is excusable or compensable, on the critcal path, and not concurrent with a non-excusable delay. Of course, for a compensible delay the contractor will also receive money. If the delay is non-excusable, the contract schedule should not be adjusted. The contractor will not receive any time or money and the owner can rightly claim liquidated or actual damages. The contractor's only recourse would be to accelerate the project to bring it back on schedule.

Concurrent delays should be analyzed in accordance with the discussions in section 2.4.3. Any non-excusable delay concurrent with any other delay will prevent the contractor from receiving time or money. An excusable delay concurrent with a compensable delay will provide the contractor with time and no money.

Criticality is also an important consideration. It must be examined to see how it is affected by the delay. If the delay is not on the critical path it is unlikely that the contractor will receive any compensation. An important consideration with respect to determining alternate critical paths is ownership of the float. Some contracts may stipulate that the float belongs entirely to the owner or that it must be shared. If shared, the float typically belongs to whoever uses it first. But, unless otherwise stated in the contract documents, float will normally belong to the contractor because he constructed the schedule and can complete the work in any manner he chooses [Rubin et al,83].

When comparing the as-planned and as-built schedules it is important to examine each delay and its impact upon the project. The impact of the delay may cause an increase or decrease in the workload of other activities. The delay may push the work into an unfavorable work season or increase the number of concurrent activites which could cause a decrease in efficiency. A time impact analysis case study is provided in Appendix II.

5.6 The Cost of Delay

Once the cause and liability of the delay have been established, and the length of delay determined, the damages sustained by the contractor must be quantified (provided the delay was compensable). The ability to quantify the costs associated with delays is largely a function of how well the delay was documented. Without good documentation, verifying delay costs is difficult at best. The most prevalent delay costs are discussed below. Understanding these costs and how they are quantified is critical to successfully resolving any delay claim.

5.6.1 Home Office Overhead

Home office overhead is one of the most difficult delay costs to determine. Items generally included in home office overhead are fixed costs such as rent, depreciation, salaried and administrative personnel, telephone, utilities, stationery, etc. Fixed costs are normally assigned by weighted proportion to the various projects which a company is undertaking during any particular time frame. Consequently, if a delay is encountered on a project, these fixed costs will continue to be incurred but the production costs to which the fixed costs are applicable will actually decrease for a given period. The result is some "unabsorbed" overhead which may be attributed to the delay [Phillip et al,88]. One method commonly used for calculating the unabsorbed overhead is the Eichleay formula introduced by the Eichleay Corporation in 1960 in a claim against the government. The following formulas succinctly describe the Eichleay method [McAlister,85]:

$$\left[\frac{\text{Contract Billings}}{\begin{array}{c}\text{Contractors Total Billings}\\ \text{for Contract Period}\end{array}}\right] \times \left[\begin{array}{c}\text{Contractors Total Overhead}\\ \text{For Contract Period}\end{array}\right] = \left[\begin{array}{c}\text{Overhead Allocable}\\ \text{to contract}\end{array}\right] \qquad (1)$$

$$\left[\frac{\text{Overhead Allocable to contract}}{\text{Contract Days of Perfomrance}}\right] = \left[\text{Daily Contract Overhead}\right] \qquad (2)$$

$$\left[\begin{array}{c}\text{Daily Contract}\\ \text{Overhead}\end{array}\right] \times \left[\begin{array}{c}\text{Number of Days}\\ \text{Delayed}\end{array}\right] = \left[\begin{array}{l}\text{Overhead Costs Allocable}\\ \text{to the delay}\end{array}\right] \qquad (3)$$

The major problem with this method is that it compensates the contractor for unabsorbed overhead whether it is rightfully applied to the delay or not. The overhead rate may have been affected by business independent of this

project or by poor management practices and consequently is not always accepted by the courts [Phillip et al,88]. Therefore, the better method would be to have the exact expenses associated with each project. Although this would require an excellent cost accounting system and may not be easily accomplished, it would certainly provide a more credible argument.

5.6.2 Field Office Overhead

The costs included for field office expenses are those which exist solely because of one particular project. Examples of field office overhead costs often encountered are supervisory and adminstrative personnel on the jobsite, utilities, trailer rental, field office equipment rental, telephones, security, and storage. These expenses would not be incurred if the project were not undertaken. For example, any on-site personnel who would be on the payroll irregardless of the project are considered as home office overhead not field office overhead. As with home office overhead it is imperative that accurate records be maintained.

5.6.3 Escalation

Escalation is the rise in cost of material, labor or equipment due to causes beyond the control of either party such as inflation or embargoes. Compensation for escalation costs are applicable only if they occur because of a delay in the contract or they are specifically allowed in the contract. Typically, escalation costs are incurred only on lengthy delays. On a large project this can be a significant factor.

5.6.4 Equipment Costs

Often when a contractor is delayed, rented or owned equipment remains idle while the delay is resolved. The idle time costs for rented equipment can be obtained directly from the invoices as long as the rental company is not a subsidiary of the contractor, in which case the standard

industry rates should be used. Determining the idle time costs for owned equipment is not so straightforward. The Associated General Contractors (AGC) publishes the Contractors Equipment Manual which provides costs associated with owning and operating equipment. The AGC manual considers such factors as average utilization, average economic life, depreciation, salvage value, initial cost, repair and maintenance costs, and interest value. Standard trade manuals contain Blue Book rates which are acceptable in some jurisdictions.[McAlister, '86]

5.6.5 Loss of Production

The costs associated with a loss in productivity are usually recoverable as long as the contractor has worked diligently. Production losses occur because of mental fatigue, stacking of trades, rescheduling, environmental conditions, learning curve factors, rework and crew changes. To determine the costs associated with a loss in productivity it is necessary to compare the production rate prior to the delay with that after delay. If the project records for making this comparison are unavailable or incomplete then industry standards can be used.

5.6.6 Interest

Interest can affect the cost of delay in two ways. First, the contractor may have to take out a loan in order to meet his current financial obligations. The interest on this loan would be recoverable if the contractor could prove the loan was necessary. Secondly, the delay will prevent the contractor from using funds due him. Accordingly, any interest lost because of delay in receipt of funds may also be a legitimate cost. However, if the delay is disputed and the case goes to court, the amount of interest returned by the courts will most likely be signifigantly less than the company's MARR (Minimum Attractive Rate of Return).

5.6.7 Insurance and Bonding Costs

It will be necessary to extend the insurance coverage to include stored materials, equipment and personnel for the period of the delay. The rates can readily be determined from the rates the contractor previously paid.

The performance and payment bonds are normally a percentage of the total project cost. Accordingly, once the final project cost has been determined bond costs can be found.

5.6.8 Non-Allowable Costs

There are several legitimate costs incurred by a contractor during the delay which are non-recoverable. These are mostly related to disputed delays which go to court. The costs of attorney's fees, claim preparation, negotiating and processing of subcontractor change orders as well as less tangible costs such as loss of credit, loss of bonding capacity, and damaged business have traditionally been denied by the courts [Phillip et al, '88].

CHAPTER 6

ACCELERATION

6.1 Introduction

There are many situations in which an owner cannot afford to have a project delayed and the only viable option is to accelerate the contract. The costs associated with acceleration are many and varied. The ability to minimize those costs requires an intimate understanding of construction costs, processes and scheduling techniques. This chapter will briefly examine the causes of acceleration and its effects on construction costs and scheduling. Additionally, manual and computer methods of compressing a construction schedule will be presented.

6.2 Causes of Acceleration

The primary cause of acceleration is delay. Many times an owner or contractor cannot afford to have a project delayed. The owner loses revenue because the property is unavailable or because additional rental or inefficiency costs are incurred for a longer period of time. The contractor will face the prospect of actual or liquidated damages and possible termination. Consequently, either party may wish to accelerate the construction schedule to avoid losing money. As discussed in chapter two, the owner may acknowledge an excusable or compensable delay and pay the contractor for the acceleration costs. This is known as actual acceleration. The owner may also put undue pressure on the contractor to finish the project on time despite the presence of an excusable or compensable delay on the critical path. In this situation the owner does not acknowledge his

responsibility for the delay and the contractor must perform work at an accelerated pace at his own cost to avoid damages or termination. Frequently, the contractor's only recourse is to obtain compensation via the contracts dispute resolution clause. If the delay is non-excusable, i.e., caused by the contractor, the contractor must bear the responsibility for the acceleration costs if the project is accelerated. If he does not accelerate, he will be subject to actual or liquidated damages or termination if the situation warrants.

Another reason to accelerate would be if the contractor or owner desired to complete the project early. The contractor may accelerate because of an opportunity to make more money on another project. However, in some instances the contractor's early completion may place a financial burden on the owner if the early completion is unexpected. For example, if a contractor completes construction on a factory substantially earlier than expected, the owner may not have the machinery for the factory. Hence, the owner may have to start making payments on the factory earlier than expected which will disrupt his cash flow [Sweet,85].

The owner may also desire project completion prior to the original contract completion date. He can direct the contractor to accelerate the project pursuant to an appropriate contract changes clause. However, accelerating a contract is extremely disruptive to a contractor's schedule and "any compensation received is surely inadaquate" [Sweet,85]. Accordingly, if acceleration is a possibility, a specific clause which indicates the limits of acceleration should be included in the contract provisions.

6.3 Effects of Acceleration

The impact of acceleration upon a construction project can be dramatic. Substantial increases in the cost of labor, material and equipment are normally encountered.

6.3.1 Labor Acceleration Costs

Additional labor costs are incurred not only through increased wage rates for overtime and shift work, but substantial costs accrue because of loss of productivity. In January, 1976 the Mechanical Contractors Association (MCA) published a bulletin which listed 16 factors affecting productivity. Each factor was assigned a percentage of loss which depended upon the severity of the conditon. Some of these factors play an important role in acceleration and will be discussed in the following sections.

6.3.1.1 Stacking of Trades

Stacking of trades is a particularly important consideration when the workspace is limited and there are many other trades working in the area simultaneously. The MCA bulletin points out that congestion of workers, difficulty in conveniently locating tools, loss of tools, additional safety hazards and increased visitors all will cause a loss in productivity. Additionally, the limited workspace may make it impossible to utilize the optimum size crew.

6.3.1.2 Morale, Fatigue, and Overtime

Lower morale and increased fatigue play a significant role where acceleration is accomplished primarily through the use of overtime. The Department of Labor conducted studies on morale and fatigue factors for projects that were placed on overtime for an extended period and they reached the following conclusions:

(1) Whatever the reason. one fact stands out clearly: The longer the hours, the more scheduled work time is lost through absenteeism.

(2) Injuries increased as the hours increased, not only in absolute, but also the rate of incidence.

(3) For hours above eight per day and 48 per week, it usually took three hours of work to produce two additional hours of output when the work was light. For heavy work, it took two hours to produce one hour of additional output.

The Business Roundtable published a Construction Industry Cost Effectiveness Task Report in November of 1980 which supported the following findings on the impact of scheduled overtime on construction projects:

(1) Placing field construction operations on a project on a scheduled overtime basis disrupts the economy of the affected area, magnifies any apparent labor shortage, reduces labor productivity, and creates excessive inflation of construction labor costs without material benefit to the completion schedule.

(2) Where a work schedule of 60 or more hours per week is continued longer that about two months, the cumulative effect of decreased productivity will cause a delay in the completion date beyond that which could have been realized with the same crew size on a 40 hour week.

(3) Where overtime operations are deemed necessary despite producitivity losses- for example on remote construction projects where bachelor housing is provided at the job site and on maintenance turnarounds- proper management can minimize inflationary effects. Management actions to be considered include use of an

additional shift and periodic shutdown of the work for a Sunday or weekend.

6.3.1.3 Job Rhythm

When a project schedule is accelerated the contractor may end up scheduling many activities concurrently. Crew personnel will change through addition or transfer which will impact job rhythm and decrease efficiency. The cost of labor will not only increase because of lost efficiency, but the contractor will also be unable to realize further increases in efficiency due to the learning curve effect [Gates,72].

6.3.1.4 Dilution of Supervision

When the contract is accelerated the project supervisors will have to reschedule work, supervise more activities at one time, provide additional guidance to reorganized crews, and expedite additional material and equipment. Hence, the supervisor will have less time to attend to his regular duties which may lead to increased errors and omissions.

6.3.2 Material Acceleration Costs

When a project schedule is accelerated, many activities are started prior to their original start date which requires that the material be on site earlier. This will frequently require compression of the transportation schedule with a concomitant increase in cost. If material is being manufactured specifically for this project, the manufacturing may also need to be accelerated.

Additional material may also be required for an accelerated schedule. For example, formwork for columns and floors can frequently be reused providing the contractor with a substantial savings. If a project is accelerated, many of these activities which were staggered, for the purpose

of reusing the formwork, may now be performed concurrently or prior to the stripping of the old forms. Hence, new forms must be purchased and cut.

6.3.3 Equipment Costs

Frequently, additional equipment may be required to accelerate the construction process. Additional cranes can be rented for moving material, placing structural steel, or providing material more quickly so that workers can proceed at an accelerated pace. Many times additional scaffolding will be required to support extra crews working at the higher elevations. If the equipment is owned by the contractor, the effect of longer work days on the equipment must be considered as a viable cost.

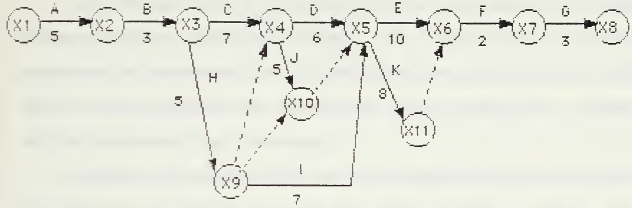
6.4 Compressing a Schedule

Compressing or crashing a schedule is the mechanism by which a contractor or owner can determine how many days a project can be accelerated and at what cost. It is essential that the person crashing the schedule be intimate with the project and extremely proficient at manipulating project schedules. A CPM schedule is an excellent environment in which to accelerate a project and fully understand the relationship between activities particularly with regard to float.

Two methods of crashing a schedule will be presented here; one for manual computation and another which utilizes linear programming techniques. Both methods require that the amount of time each activity can be compressed and the cost for each day of compression be known.

6.4.1 Compressing a Schedule Manually

Accelerating a project schedule manually can be a very time consuming process requiring a vast amount of skill and expert judgement, particularly with large projects. The best manner in which to illustrate the process is by example. Figure 6.1 depicts an eleven activity CPM diagram



ACTIVITY	FREE FLOAT	AVAILABLE COMPRESSION DAYS	COST
A	0	0	0
B	0	2	150
C	0	3	300
D	0	3	450
E	0	5	600
F	0	1	200
G	0	1	200
H	0	2	150
I	1	3	300
J	1	2	400
K	2	4	VAR

Activity K Compression Schedule:

From 8 days To 6 days 100

From 8 days To 4 days 175

From 6 days To 4 days 250

FIGURE 6.1 CPM Diagram for the Example Problem

and the amount of days each activity can be compressed with its concomitant cost.

The cost and location of the activity to be compressed are the most important factors in crashing a schedule. The cheapest activity should be considered for compression first. In that manner the cost versus time trade-off for every compression can be analyzed. For this example the schedule will be compressed to its fullest extent.

In order to be of any benefit the activity must be on the critical path. Compressing an activity that is not on the critical path does not shorten the project duration and is obviously a waste of money. Also, activities on the critical path which can be compressed without affecting any other activity should be considered for compression first.

From Figure 6.1 it can be seen that activity B is the cheapest critical path activity which affects no other activity. Accordingly, it is compressed first for two days at a total cost of $300. For the same reasons activities F and G would be compressed next. Although activity H is cheaper to compress than F and G it would not be compressed at this time because it is not on the critical path. The next step requires some deftness in manipulating schedules because at first glance it appears that there are several paths on which to proceed. Activities C, D, and E are all on the critical path. Because activity C is the cheapest it will be selected first. Acivity C can be compressed up to three days, however, if compressed more than one day activities C and D will no longer be critical and the critical path will flow through activities H and I. Hence, activity C should be compressed for one day only and there will now be two critical paths. Activities C, D, H, and I now form a block and must be compressed with respect to both critical paths. Several combinations can now be considered: C and H, C and I, D and

I, and D and H. Activity E should also be considered. Activity C and H represent the cheapest alternative and are selected for two days of compression. The only remaining alternatives for critical path compression are activities D and H, and activity E. Activity E is the less costly alternative but is compressed for only two of the available five days because after two days it becomes non-critical and activity K becomes critical. Again the activity D and I combination is available but a new critical path combination of activities E and K also exists. The E-K combination is cheaper and is selected first. It should be noted that activity K has a variable compression cost and because of its configuration activity E can be compressed only two of its three available days and K only two of its four available days. The only critical path compression available at this point is combination of activities D and I. Once this combination is compressed, activity J becomes critical. The final compression of two days may be taken from the combination of activities D, J, and I. The only compression days remaining are those for activities E and K and they are unusable. A summary of the steps taken to compress this schedule are shown in tables 6.1 and 6.2. This table also illustrates the costs associated with each compression that are essential for making the time versus cost trade off decisions.

Compressing a schedule manually can be arduous and very un-appealing method for use on large construction projects. Additionally, if this method of compression is followed there is no guarantee that the resulting compression will be the maximum amount of time at the minimum cost. However, it is good for providing important time versus cost trade-off information and is better suited for dealing with complex cost schedules than linear programming.

TABLE 6.1 Remaining Float and Compression Days from Schedule Compression

ACTIVITY	FREE FLOAT REMAINING	DAYS OF COMPRESSION REMAINING
A	0	0
B	0	0
C	0	0
D	0	0
E	0	1
F	0	0
G	0	0
H	0	0
I	0	0
J	0	0
K	0	2

TABLE 6.2 Summary of Compression Steps

COMPRESSION	ACTIVITIES	DAYS	AMOUNT
1	B	2 @ 150	300
2	F	1 @ 200	200
3	G	1 @ 200	200
4	C	1 @ 300	300
5	C,H	2 @ 450	900
	C,I	600	
	D,I	750	
	D,H	600	
	E	600	
6	E	2 @ 600	1200
7	D,I	750	
	E,K	2 @ 700	1400
8	D,I	1 @ 750	750
9	D,I,J	2 @ 1150	2300

6.4.2 Schedule Compression with Linear Programming

Linear programming is an attractive alternative to compressing a construction schedule. It is readily adaptable to CPM schedules and fixed compression costs. However, it does not provide time versus cost trade off information and programming becomes increasingly difficult with the addition of variable costs. LINDO, a program used for solving linear, integer, and quadratic programming problems, was utilized for solving the example in figure 6.1 [Winston,87].

A linear program for schedule compression requires the development of an objective function and a set of constraints within which the optimum solution lies. The objective function for compressing a schedule is to minimize the cost of compression. The constraints define the relationships between activities and the amount of time the schedule is to be compressed.

Initally, a program will be developed to illustrate the construction of a CPM schedule within the linear programming environment. The objective function is to minimize the time between the first node X1 and the final node X8. The constraints merely define the relationships between the activities. For example, constraint (2) states that X2 must be greater than or equal to X1 plus the duration of activity A which is five days. In this manner the critical path or longest duration can be determined. The program and its results are provided in figure 6.2.

The critical path program can now be altered to determine the minimum compression cost. This program is given in figure 6.3. The number of days each activity is to be compressed is represented by the letter of each activity, A, B, C, etc.. Associated with each letter is the cost of

Linear Program

```
MIN      X8 - X1

SUBJECT TO

        2)  - X1   +  X2   >=   5
        3)  - X2   +  X3   >=   3
        4)  - X3   +  X9   >=   5
        5)  - X3   +  X4   >=   7
        6)  - X9   +  X4   >=   0
        7)  - X4   +  X10  >=   5
        8)  - X4   +  X5   >=   6
        9)  - X10  +  X5   >=   0
       10)  - X9   +  X11  >=   7
       11)  - X5   +  X6   >=  10
       12)  - X11  +  X6   >=   8
       13)  - X6   +  X7   >=   2
       14)    X8   -  X7   >=   3
       15)  - X5   + X11   >=   0

END
```

Results

```
        LP OPTIMUM FOUND  AT STEP     13

            OBJECTIVE FUNCTION VALUE

                  36.0000000

     VARIABLE          VALUE            REDUCED COST

         X8          36.000000           .000000
         X1            .000000           .000000
         X2           5.000000           .000000
         X3           8.000000           .000000
         X9          13.000000           .000000
         X4          15.000000           .000000
        X10          21.000000           .000000
         X5          21.000000           .000000
        X11          21.000000           .000000
         X6          31.000000           .000000
         X7          33.000000           .000000
```

FIGURE 6.2 Linear Program for Determining Critical Path

```
OBJECTIVE FUNCTION

MIN    150 B + 300 C + 450 D + 600 E + 200 F + 200 G +
       150 H + 300 I + 400 J + 175 K1 + 100 K2 + 250 K3

SUBJECT TO

ACTIVITY CONTRAINTS

         2) - X1  +  X2          >=  5
         3) - X2  +  X3  +  B    >=  3
         4) - X3  +  X9  +  H    >=  5
         5) - X3  +  X4  +  C    >=  7
         6) - X9  +  X4          >=  0
         7) - X4  +  X10 +  J    >=  5
         8) - X4  +  X5  +  D    >=  6
         9) - X10 +  X5          >=  0
        10) - X9  +  X5  +  I    >=  7
        11) - X5  +  X6  +  E    >=  10
        12) - X6  +  X7  +  F    >=  2
        13)   X8  -  X7  +  G    >=  3
        14) - X11 +  X6          >=  0

COMPRESSION RESTRICTIONS

        15)    B <=   2
        16)    C <=   3
        17)    H <=   2
        18)    D <=   3
        19)    J <=   2
        20)    I <=   3
        21)    E <=   5
        22)    F <=   1
        23)    G <=   1

DESIRED DURATION CONSTRAINT

        24)    X8   -   X1   <=   22

CONSTRAINTS FOR VARIABLE COSTS

        25) - X5  +  X11 +  K    >=   8
        26) - 4Y  +  K1  =     0
        27) - 2Y1 +  K2  =     0
        28) - 2Y2 +  K3  =     0
        29)     Y +  Y1  <=    1
        30)     Y +  Y2  <=    1
        31) -  K1 -  K2 - K3 + K =    0

 END
 INTEGER-VARIABLES=       3
```

FIGURE 6.3 Linear Program for Compressing the Example Schedule

its compression, i.e., 0A, 150b, 300C, etc.. The three variable costs associated with activity K are included as seperate variables.

The activity constraints of the previous problem are easily adjusted to include the number of days any activity is compressed. As an example, constraint (3) changes from **-X2 + X3 >= 3** to **-X2 + X3 + B >= 3** to account for the number of days activity B is compressed. To limit the number of days each activity could be compressed, constraints (2) to (14) were included. For example, activity D can only be compressed three days hence the constraint is **D <= 3**. Special constraints had to be included for for the variable costs because they each were limited to only two values and they are included as contraints (15) through (23). The final major constraint that must be included is the duration. In other words, the user must know beforehand the number of days to compress the schedule. Accordingly, if a time-cost trade off analysis is desired, a separate run is required for each day of compression.

The maximum compression determined by the manual calculations was used as the inital duration for the linear program. The results, shown in figure 6-4, indicate that the schedule can be compresssed for only $7200 vice the $7550 determined by manual calculations. Additionally, inspection of figures 6-3 and 6-4 indicates that activities I, J, and D are all on separate critical paths and still have at least one day of compression remaining. Accordingly, the entire schedule can be compressed one additional day at a cost of $1150.

```
LP OPTIMUM FOUND  AT STEP      7

     OBJECTIVE FUNCTION VALUE

      TOTAL COST  7200.00000

VARIABLE        NODE VALUE          REDUCED COST

     Y          1.000000             .000000
    Y1           .000000             .000000
    Y2           .000000             .000000
    X8         22.000000             .000000
    X1           .000000             .000000
    X2          5.000000             .000000
    X3          6.000000             .000000
    X9          9.000000             .000000
    X4         10.000000             .000000
   X10         14.000000             .000000
    X5         14.000000             .000000
   X11         15.000000             .000000
    X6         19.000000             .000000
    X7         20.000000             .000000

DAYS OF COMPRESSION USED FOR EACH ACTIVITY

     B          2.000000             .000000
     C          3.000000             .000000
     D          2.000000             .000000
     E          5.000000             .000000
     F          1.000000             .000000
     G          1.000000             .000000
     H          2.000000             .000000
     I          1.000000             .000000
     J          1.000000             .000000
    K1          4.000000             .000000
    K2           .000000             .000000
    K3           .000000             .000000
     K          4.000000             .000000
```

FIGURE 6.4 Results of 14 Day Schedule Compression

CHAPTER 7

An Acceleration Case Study

7.1 Introduction

In this chapter the acceleration of construction on the Air Force One maintenance and support complex at Andrews Air Force Base in Camp Springs, Maryland, will be examined. This facility will support two new Boeing 747 Presidential airplanes and one C-9 aircraft. The 19,400 square foot facility provides a presidential pilots area, flight crew area, kitchen area, aircraft maintenance area, as well as administrative and logisitic support areas. Additionally, a security system will be installed to protect the Air Force One aircraft from sabotage, espionage, crime, or attack. The location of the base and hangar are detailed in figures 7.1 and 7.2. The final construction costs are estimated to be in excess of $41 million.

7.2 Background

The George Hyman Construction Company founded in 1906 served as prime contractor on this project and was awarded the contract on 13 April 1987 on the basis of a competitive negotiation. Hyman averaged 20 projects a year during the previous three years, with an annual WIP of nearly $400 million. Hyman is a diversified general contractor with experience in many types of construction including transportation, pollution control, industrial, health care, mixed use, hotel, renovation and office buildings. The Naval Facilities Engineering Command, Cheasapeake Division, served as the construction agency for the project. The Resident Officer in Charge of Construction provided the construction surveillance and processed the bulk

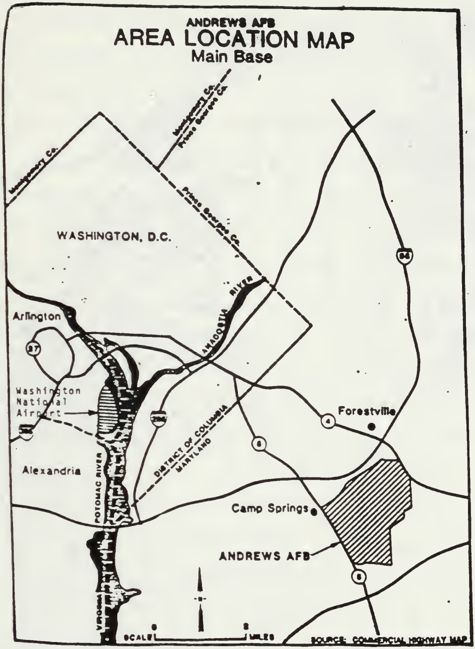


FIGURE 7.1 Area location of Air Force One Maintenance and Support Complex [NAVFAC,87]

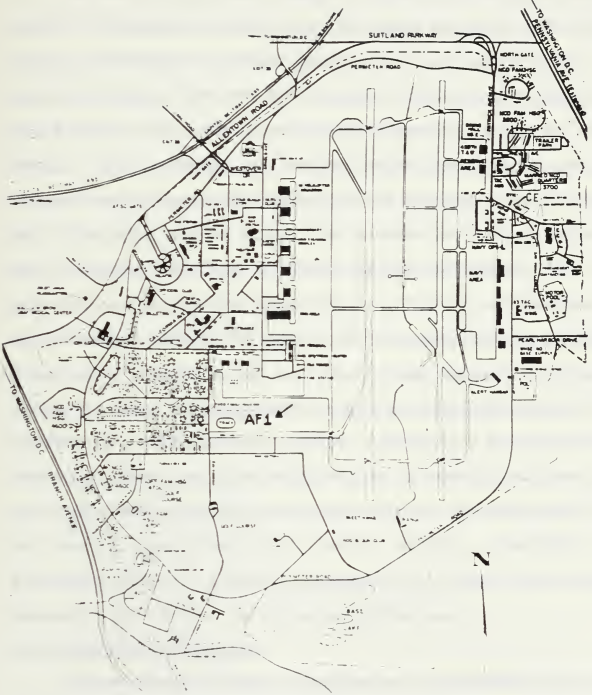


FIGURE 7.2 Site location of Air Force One Maintenance and Support Complex [NAVFAC,87]

of the contract modifications including the contract acceleration change order.

The construction process began on 28 April 1987 with the notice to proceed. Throughout the first year the project was beset with several contract modifications including design errors and omissions and user requested changes. However, the only delay which impacted the critical path was due to unusually severe weather encountered during the winter months. After reviewing the weather records and daily reports, the contractor and the government agreed that the contractor suffered 22 work days of legitimate weather delay. This extended the contract completion date 30 calendar days from 19 October 1988 to 18 November 1988. The first of the new presidential planes was due to arrive in late November but the government required the facilities for one month following substantial completion to prepare for the new plane. Other hangars would not be suitable for storing and maintaining the large and technically advanced new plane nor for providing adaquate security. Additonally, if the plane was not accepted and moved out of the Boeing facilities on schedule, the government would incurr substantial costs for storing the plane at the Boeing facility and for delaying construction of the second aircraft. Accordingly, the government decided to accelerate construction by 22 work days to permit turnover of the facility by the original completion date.

7.3 Accelerating the Schedule

The government's primary consideration in accelerating this project was selecting the least costly critical path activities to achieve the desired completion date at the lowest cost. However, the contractor's main goal was to accelerate those activities in which he had the greatest amount of risk, primarily those activities which are subject to future resource criticality or

possible weather delays. There is an obvious conflict in these objectives. Additionally, the contractor was in the better negotiating position because the government must accelerate or they would suffer signifcant monetary losses. Accordingly, the activities to be compressed were negotiated as well as the number of days and concomitant costs.

During negotiations, several impacts of acceleration were given careful consideration. The work being accelerated in the confined areas was a primary concern. For example, several trades had to work in the hangar ceiling area concurrently without interfering with each another. A detailed path with specific target dates had to be developed for each trade to ensure not only adaquate workspace but also maintain an appropriate order of construction. Impacts on non-critical activities such as the mezzanine rough-in and the POL facility mechanical work were also negotiated. Additionally, the most costly activities such as site work and installation of the hangar doors were prevented from becoming critical. The following is a list of the negotiated impact items:

(1) Fireproof columns
(2) Mobilization for precast panels
(3) Project management
(4) Contingency funds
(5) AFFF overhead piping
(6) AFFF/Mechanical/Plumbing/ATC trim out
(7) Roof drains
(8) AFFF testing
(9) Hot water system
(10) Mezzanine rough-in
(11) POL facility mechanical work
(12) Overhead electrical lines and light fixtures
(13) Electrical/Life safety/Security trim out
(14) Security system
(15) Final adjustment hangar doors (electrical)
(16) Fence post and fabric installation

(17) Hanger door fabrication
(18) CD door and AB siding
(19) Panel activities
(20) Paint CMU, walls, ceiling, trusses
(21) Structural steel

The following sections will highlight the important acceleration issues negotiated for many of the construction impacts listed above. The information was obtained from contract files at the Naval Facility Engineering Command (NAVFAC), Cheasapeake Division [NAVFAC,87] and through interviews of the on-site personnel. Appendices III and IV contain construction schedules which depict the accelerated activities for the original and compressed schedules respectively.

7.3.1 Fireproof Columns (Activities 545-546, 548-549-550)

All the work on the fireproof columns would be accelerated utilizing overtime hours and Saturdays. Each activity was compressed from 15 days to 10 days to allow the curtain wall and hangar door subcontractor to work without interruption. Also, additional scaffolding and platforms had to be rented for finishing the concrete columns. The contractor had included the entire cost of the additional scaffold rental and purchase of finishing platforms and column forms in his price for acceleration. The government countered that there should be no increase because the rental period for the original scaffolding would be shorter. The contractor agreed the governments position on the scaffolding was reasonable but claimed he bought far more finishing platforms and forms than previously required and should be compensated. The government agreed to compensate the contractor for the formwork but argued that the finishing platforms made his workers more efficient and agreed to pay only for those platforms required by the acceleration.

7.3.2 Precast Panels (584-586-616-618-619-930-931-935-678)

The precast panel activities were accelerated by having them installed as soon as an individual work area became available. Originally, all work areas were to be completed prior to installation. Accordingly, additional labor costs were incurred for mobilizing the scaffolding three additional times.

7.3.3 Project Management

The project management costs negotiated with the prime contractor included preparation costs, second shift supervising, and several miscellaneous costs associated with the negotiation of the hangar door acceleration.

7.3.4 Contingency Costs

The government and the prime contractor both agreed to include contingency costs of $35,000 but for different reasons. The government's position was that the project had the potential to be ten days late and therefore agreed to compensate the contractor for this risk by providing 10 days of liquidated damages at $3500 per day for a total contingency of $35,000. The contractor proposed contingency costs of $35,560 primarily for additional costs that would be incurred by the painting subcontractor should the work not be available to him because of another subcontractor. The contractor agreed to reduce this contingency totally or in part once it had been determined that a specific contingency cost would not be required.

7.3.5 AFFF Overhead Piping (636-638)

Originally this activity was not critical but when the schedule was adjusted for the acceleration it became critical. The activity duration was shortened to 48 days and the work could not begin until 25 April. Access to the work area would not be granted until then. The labor for the work

would be done in two shifts, therefore efficency factors were not applicable. Additional rental costs for a crane were also negotiated.

7.3.6 Trim Out of Sprinklers/Plumbing System (468-470-472)

This activity was accelerated through overtime work. The contractor proposed a 30% inefficency rate while the government argued that 8% was the only reasonable inefficency rate listed for overtime. After detailed discussions of the specifics of the work both parties agreed to an inefficiency of 17% for the overtime work.

7.3.7 Roof Drains (901-903-905)

On Schedule1 the roof drains were not critical and scheduled to follow roof drain activities 925 and 929. However, in the process of compressing the schedule the roof drain activities became critical. To alleviate this problem a second crew would be brought in to work concurrently with the crew performing activities 927-928-929. An 80% efficiency factor for working multiple crews was negotiated. An additional set of scaffolds and support equipment were also required to accelerate these activities.

7.3.8 AFFF Testing (697-699,706-708)

The AFFF testing activities were originally a critical path item. To alleviate congestion problems the parties agreed to have the testing performed during a night shift and on two Saturdays. The contractor proposed a 10% inefficiency rate for the night shift as well as a standard 15% shift differential. Additionally, the contractor included costs for portable light towers he claimed were necessary since the sprinkler heads were above the high bay lights. The government accepted the additional costs for the shift differential and the light towers but argued that there were no applicable inefficencies. A very small inefficency was agreed upon to cover the minor inefficencies associated with night shift work.

7.3.9 Impacted Mechanical Activities

In his proposal the contractor indicated that the mezzanine rough-in and the POL facility mechanical work would be impacted by the project acceleration. Originally the contractor had scheduled all of his work sequentially but because of the acceleration would now have to perform these activities concurrently with other activities. Accordingly, these activities would be impacted by diluted supervision and learning curve effects for mobilizing a new crew. The contractor proposed a 30% inefficency factor for the POL facility and a 33% inefficency factor for the mezzanine deck. The government countered that 15% each was adequate to cover the inefficencies while learning curve effects should only be included once. Both parties agreed to a 25% inefficency factor for the mezzanine deck accounting for diluted supervision and learning curve impacts. Also agreed upon was a 13% inefficency rate for diluted supervision on the POL facility.

7.3.10 Electrical Work

All of the electrical activities previously listed were accelerated by the use of overtime and Saturday work. The contractor utilized an efficency factor of 75% for the overtime work in addition to the standard 85% efficency rate normally applied to electrical work in high bay areas. The government used an 85% efficency factor for overtime work based on the 1980 Business Roundtable Report. This was the efficency agreed upon. The overhead electrical lines and light fixture activities (626-628-630) were the only accelerated electrical activities originally on the critical path. The others became critical during the compression of the schedule.

7.3.11 Hangar Door Subcontractor

Originally the hangar door erections were on the critical path and therefore had to be accelerated if construction was to be completed by 19

Oct 88. Accelerating the installation of the hangar doors proved to be too costly. Accordingly, the government sought another area in which to compress the schedule. The alternative proposed by the government was to alter the fabrication of the doors at the factory so that the doors could be fabricated and installed sequentially. This would require additional work for the door manufacturer as the door jigs would have to be broken down to allow for complete fabrication of each door individually rather than fabricating identical pieces for both hangar doors at the same time. A 25% ineffficency rate was utilized and it was assumed that all additional work would be accomplished on overtime. Also, additional transportation costs were incurred due to the extra delivery trip required. With the adjustment in the fabrication and delivery schedules this activity was no longer critical and in fact now had 20 days of float. The contractors proposal for accelerating the installation of the hangar doors was $80,000 while the cost of this alternative was only $6,000.

7.3.12 Wall Panel Subcontractor

All the wall panel and siding activities for the AB and CD doors were originally on the critical path. The contractor proposed compressing the schedule by adding two additional five man crews and a supervisor. The government thought it was cheaper to have the existing crew work 10 hour days and 5 Saturdays at an 85% efficiency rate than pay for learning curve losses and an additional supervisor. The parties agreed to have the original crews work overtime and Saturdays and add one crew to make up for the 15% inefficiency. Equipment costs were also incurred for additional scaffolding for the extra crew.

7.3.13 Structural Steel Contractor

The number of days lost in the structural steel activity due to unusally severe weather was 6 days. This is an excusable delay and would normally entitle the contractor to a 6 day time extension. However, in order to keep the structural steel contractor ahead of the other trades in the high bay area, both parties agreed to have the contractor work four Saturdays to make up for the lost time. The prime contractor agreed to pay for one Saturday and forego overhead and profit as he would save overhead and equipment rental costs that he normally would have had to absorb for an excusable delay.

CHAPTER 8

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 Summary

This report has defined and categorized delay as well as discussed many of its causes and effects. Many of the risks which lead to construction delay have been analyzed and recommendations for transferring these risks to minimize or avoid delay were provided. An expert system was presented to aid the owner or CM in determining the most probable cause of delay and provide recomendations for reducing the possibility of delay. Unfortunately, delay is inevitable on many projects and the fundamental issues in analyzing construction delay and its associated costs were also presented. On many occassions delay cannot be tolerated. Methods of compressing a schedule and the associated costs were examined in detail. A case study of an acceleration implemented during construction of the new Air Force One hangar was also presented.

8.2 Conclusions

1. Construction delay is here to stay and the more that owners and construction managers know about delay the better they will be able to manage it.

2. The owner is in the best position to ensure that construction risks are minimized because he selects the designer and contractor and defines their relationship.

3. Selecting the appropriate contract type, properly allocating contract risks, and prequalifying the designer and contractor can help minimize project costs and the possibility of future delays.

4. The prototype expert system can help the owner or determine the area of most probable delay and provide recommendations for avoiding or eliminating delay. Additionally, it may be used as a resource for examining the various areas of delay.

5. The manual method of compressing a construction schedule presented in Chapter Six can become cumbersome for large projects and does not guarantee maximum compression at the minimum cost. However, it is useful in smaller applications with complex constraints.

6. Compressing a schedule through linear programming will provide accurate results, however, it can be exceedingly difficult to use if the project schedule or costs are complex.

7. Successfully managing construction acceleration requires a solid understanding of scheduling fundamentals and construction processes as evidenced by the acceleration of the Air Force One project.

8.3 Recommendations for Future Research

1. **Use of the expert system in a practical application for validation** - A study which would distribute the expert system to several CM's and owners for application to various types of construction projects. Analyze the projects for possible delays avoided because of the program and also for any delays which occurred. Compare the results to the delays encountered on similar types of projects which did not have the benefit of the program. What were the differences in cost? What changes should be made to improve the system?

2. **Utilizing the expert system as an educational tool** - Modify the current expert system so that it could be used as a tool for training and educating future owners and construction managers in avoiding or minimizing construction delay.

3. **Computer techniques for schedule compression** - Conduct a study of computer programs available on the market which can readily be adapted to compressing large construction schedules with complex cost and time components.

4. **Development of an expert system for construction acceleration** - A vast amount of deftness is required for manipulating schedules and costs associated with schedule compression. The experts have many tricks and caveats for selecting specific activities for compression which cannot always be factored into algorithmic computer programs. Additionally, the experts have considerable knowledge about specific impact costs associated with compressing different construction activities.

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APPENDICES

1. Appendix I - An expert system for Assisting the Owner in Minimizing or Avoiding Construction Delay. Hard copy and diskette included.

2. Appendix II - A case-study illustrating the principles for analyzing the CPM schedule for a project with several concurrent delays.

3. Appendix III - CPM schedule which includes the impact of delay on the compressed activities prior to acceleration.

4. Appendix IV - CPM schedule subsequent to the negotiated acceleration.

APPENDIX I

Production Rule Language for the Expert System from the Insight 2+ Editor

TITLE Construction Delay DISPLAY

AN EXPERT SYSTEM FOR ASSISTING THE OWNER IN MINIMIZING OR AVOIDING CONSTRUCTION DELAY

DEVELOPED BY

STEVE BERTOLACCINI

>>> PRESS F1 TO CONTINUE <<<

GENERAL INFORMATION

THIS PROGRAM IS PRIMARILY INTENDED FOR AN OWNER OF A FUTURE PROJECT WHO HAS LIMITED KNOWLEDGE OF THE CONSTRUCTION PROCESS. IT IS INTENDED TO BE USED DURING PRECONSTRUCTION PHASE, AFTER A DEVELOPER AND SITE HAVE BEEN ATTAINED, BUT BEFORE DESIGNER AND CONTRACTOR CONTRACTS HAVE BEEN FINALIZED.

THE LOGIC OF THE PROGRAM IS FAIRLY STRAIGHTFORWARD. THREE STEPS ARE NECESSARY FOR ALL BRANCHES OF THE PROGRAM. FIRST, THE GENERAL AREA OF MOST PROBABLE DELAY, SECOND, THE SPECIFIC AREA OF MOST PROBABLE DELAY WITHIN THE GENERAL AREA, AND FINALLY, THE RECOMMENDED ACTIONS TO ELIMINATE OR MINIMIZE THE DELAY.

TO OBTAIN THE GENERAL AREA OF MOST PROBABLE DELAY, TWO PATHS EXIST. THE OWNER MAY DIRECTLY SELECT A PARTICULAR AREA HE WANTS TO STUDY, OR HAVE THE PROGRAM DETERMINES THE MOST PROBABLE AREA OF DELAY FROM A GENERAL POOL OF QUESTIONS.

>>> PRESS F1 TO CONTINUE <<<

AFTER THE GENERAL AREA OF MOST PROBABLE DELAY HAS BEEN FOUND, A SERIES OF DETAILED QUESTIONS IN THAT AREA ARE ASKED TO DETERMINE THE SPECIFIC AREA OF MOST PROBABLE DELAY. AFTER THE SPECIFIC AREA OF MOST PROBABLE DELAY IS DETERMINED, A RECOMMENDATION OF ACTION IS AUTOMATICALLY GIVEN.

USER INPUT INFORMATION

ALL INPUT IS USER FRIENDLY AND SELF EXPLANITORY. THE

USER WILL BE GIVEN EITHER A STATEMENT OR A MENU FROM WHICH TO CHOOSE. IF GIVEN A STATEMENT THEN THE USER MUST ALSO PROVIDE HIS LEVEL OF CONFIDENCE THAT THE STATEMENT IS TRUE. ONE HUNDRED PRERCENT INDICATES THE STATEMENT IS COMPLETELY TRUE, WHILE TWO PERCENT INDICATES THE STATEMENT IS COMPLETELY FALSE. IF CONFIDENCES LESS THAN TWO PERCENT ARE ENTERED THE PROGRAM WILL TERMINATE.

>>>PRESS F1 TO CONTINUE<<<

SELECT FROM A MENU BY USING THE UP AND DOWN ARROWS AND THEN <RETURN>. SELECT A CONFIDENCE INTERVAL BY USING THE LEFT AND RIGHT ARROW KEYS TO CHANGE THE SIZE OF THE CONFIDENCE INTERVAL BAR AND THEN <RETURN>.

>>> PRESS F3 TO START THE PROGRAM <<<

```
OBJECT Q
AND M
AND N
AND O
AND P

THRESHOLD = 1

CONFIDENCE WEATHER
AND POLITICAL
AND LABOR
AND MATERIAL
AND FINANCIAL
AND BORROWING CAPACITY
AND PROJECT NEED
AND OWNER INVOLVEMENT
AND EXPERIENCE
AND CAPACITY
AND FAST TRACK
AND COMPLEX
AND HISTORY
AND FINANCIAL STABILITY
AND SIZE and CAPACITY
AND MANAGEMENT
AND AA1
AND AA2
AND AA3
AND AA4
AND AA5
AND AA6
AND AB1
AND AB2
AND AB3
AND AB4
AND AB5
AND AB6
AND AC1
AND AC2
AND AC3
```

```
AND AC4
AND AC5
AND AC6
AND AD1
AND AD2
AND AD3
AND AD4
AND AD5
AND AD6

SUPPRESS ALL

1.  goal

RULE 100
IF would you like to\A
THEN Z

RULE 105
IF would you like to\B
THEN Y
AND DISPLAY XXX

RULE 215
IF Z
AND Q\UNC
THEN AW

RULE 220
IF Z
AND Q\OWN
THEN AX

RULE 225
IF Z
AND Q\AE
THEN AY

RULE 230
IF Z
AND Q\CONTRACTOR
THEN AZ

RULE 233A
IF AW
AND M\AA11
THEN GOAL
AND DISPLAY RA1

RULE 233B
IF AW
AND M\AA21
THEN GOAL
AND DISPLAY RA2
```

```
RULE 233C
IF AW
AND M\AA31
THEN GOAL
AND DISPLAY RA3

RULE 233D
IF AW
AND M\AA41
THEN GOAL
AND DISPLAY RA4

RULE 233E
IF AW
AND M\AA51
THEN GOAL
AND DISPLAY RA5

RULE 233F
IF AW
AND M\AA61
THEN GOAL
AND DISPLAY RA6

RULE 233G
IF AX
AND N\AB11
THEN GOAL
AND DISPLAY RB1

RULE 233H
IF AX
AND N\AB21
THEN GOAL
AND DISPLAY RB2

RULE 233I
IF AX
AND N\AB31
THEN GOAL
AND DISPLAY RB3

RULE 233J
IF AX
AND N\AB41
THEN GOAL
AND DISPLAY RB4


RULE 233K
IF AX
AND N\AB51
THEN GOAL
AND DISPLAY RB5
```

```
RULE 233L
IF AY
AND O\AC11
THEN GOAL
AND DISPLAY RC1

RULE 233M
IF AY
AND O\AC21
THEN GOAL
AND DISPLAY RC2

RULE 233N
IF AY
AND O\AC31
THEN GOAL
AND DISPLAY RC3

RULE 233O
IF AY
AND O\AC41
THEN GOAL
AND DISPLAY RC4

RULE 233P
IF AY
AND O\AC51
THEN GOAL
AND DISPLAY RC5

RULE 233Q
IF AY
AND O\AC61
THEN GOAL
AND DISPLAY RC6

RULE 233R
IF AZ
AND P\AD11
THEN GOAL
AND DISPLAY RD1

RULE 233S
IF AZ
AND P\AD21
THEN GOAL
AND DISPLAY RD2

RULE 233T
IF AZ
AND P\AD31
THEN GOAL
AND DISPLAY RD3
```

```
RULE 233U
IF AZ
AND P\AD41
THEN GOAL
AND DISPLAY RD4

RULE 233V
IF AZ
AND P\AD51
THEN GOAL
AND DISPLAY RD5

RULE 233V
IF AZ
AND P\AD61
THEN GOAL
AND DISPLAY RD6

RULE 110
IF Y
AND WEATHER
AND A1:=CONF(WEATHER)
THEN Y1

RULE 120
IF Y1
AND POLITICAL
AND B1:= CONF(POLITICAL)
THEN Y2

RULE 125
IF Y2
AND LABOR
AND C1:=CONF(LABOR)
THEN Y3

RULE 130
IF Y3
AND MATERIAL
AND D1:=CONF(MATERIAL)
THEN Y4

RULE 131
IF Y4
AND E1:=(A1+B1+C1+D1)/4
THEN X

RULE 135
IF X
AND FINANCIAL
AND A2:=CONF(FINANCIAL)
THEN X1
```

```
RULE 140
IF X1
AND BORROWING CAPACITY
AND B2:=CONF(BORROWING CAPACITY)
THEN X2

RULE 145
IF X2
AND PROJECT NEED
AND C2:=CONF(PROJECT NEED)
THEN X3

RULE 150
IF X3
AND OWNER INVOLVEMENT
AND D2:=CONF(OWNER INVOLVEMENT)
THEN X4

RULE 151
IF X4
AND E2:=(A2+B2+C2+D2)/4
THEN W

RULE 155
IF W
AND EXPERIENCE
AND A3:=CONF(EXPERIENCE)
THEN W1

RULE 160
IF W1
AND CAPACITY
AND B3:=CONF(CAPACITY)
THEN W2

RULE 165
IF W2
AND FAST TRACK
AND C3:=CONF(FAST TRACK)
THEN W3

RULE 170
IF W3
AND COMPLEX
AND D3:=CONF(COMPLEX)
THEN W4

RULE 171
IF W4
AND E3:=(A3+B3+C3+D3)/4
THEN V
```

```
RULE 175
IF V
AND HISTORY
AND A4:=CONF(HISTORY)
THEN V1

RULE 180
IF V1
AND FINANCIAL STABILITY
AND B4:=CONF(FINANCIAL STABILITY)
THEN V2

RULE 185
IF V2
AND SIZE and CAPACITY
AND C4:=CONF(SIZE and CAPACITY)
THEN V3

RULE 190
IF V3
AND MANAGEMENT
AND D4:=CONF(MANAGEMENT)
THEN V4

RULE 191
IF V4
AND E4:=(A4+B4+C4+D4)/4
THEN U

RULE 195
IF U
AND E1 >= E2
AND E1 >= E3
AND E1 >= E4
THEN AA
AND DISPLAY ONE

RULE 200
IF U
AND E2 >= E1
AND E2 >= E3
AND E2 >= E4
THEN AB
AND DISPLAY TWO

RULE 205
IF U
AND E3 >= E1
AND E3 >= E2
AND E3 >= E4
THEN AC
AND DISPLAY THREE
```

```
RULE 210
IF U
AND E4 >= E1
AND E4 >= E2
AND E4 >= E3
THEN AD
AND DISPLAY FOUR

RULE 235
IF AA
AND ASK AA1
AND ASK AA2
AND ASK AA3
AND ASK AA4
AND ASK AA5
AND ASK AA6
THEN TA

RULE 240
IF AB
AND ASK AB1
AND ASK AB2
AND ASK AB3
AND ASK AB4
AND ASK AB5
THEN TB

RULE 245
IF AC
AND ASK AC1
AND ASK AC2
AND ASK AC3
AND ASK AC4
AND ASK AC5
AND ASK AC6
THEN TC

RULE 250
IF AD
AND ASK AD1
AND ASK AD2
AND ASK AD3
AND ASK AD4
AND ASK AD5
AND ASK AD6
THEN TD

RULE 255
IF TA
AND CONF(AA1) >= CONF(AA2)
AND CONF(AA1) >= CONF(AA3)
AND CONF(AA1) >= CONF(AA4)
AND CONF(AA1) >= CONF(AA5)
AND CONF(AA1) >= CONF(AA6)
THEN goal
AND DISPLAY RA1
```

```
RULE 260
IF TA
AND CONF(AA2) >= CONF(AA1)
AND CONF(AA2) >= CONF(AA3)
AND CONF(AA2) >= CONF(AA4)
AND CONF(AA2) >= CONF(AA5)
AND CONF(AA2) >= CONF(AA6)
THEN goal
AND DISPLAY RA2

RULE 265
IF TA
AND CONF(AA3) >= CONF(AA1)
AND CONF(AA3) >= CONF(AA2)
AND CONF(AA3) >= CONF(AA4)
AND CONF(AA3) >= CONF(AA5)
AND CONF(AA3) >= CONF(AA6)
THEN goal
AND DISPLAY RA3

RULE 270
IF TA
AND CONF(AA4) >= CONF(AA1)
AND CONF(AA4) >= CONF(AA2)
AND CONF(AA4) >= CONF(AA3)
AND CONF(AA4) >= CONF(AA5)
AND CONF(AA4) >= CONF(AA6)
THEN goal
AND DISPLAY RA4

RULE 271
IF TA
AND CONF(AA5) >= CONF(AA1)
AND CONF(AA5) >= CONF(AA2)
AND CONF(AA5) >= CONF(AA3)
AND CONF(AA5) >= CONF(AA4)
AND CONF(AA5) >= CONF(AA6)
THEN goal
AND DISPLAY RA5

RULE 272
IF TA
AND CONF(AA6) >= CONF(AA1)
AND CONF(AA6) >= CONF(AA2)
AND CONF(AA6) >= CONF(AA3)
AND CONF(AA6) >= CONF(AA4)
AND CONF(AA6) >= CONF(AA5)
THEN goal
AND DISPLAY RA6
```

```
RULE 275
IF TB
AND CONF(AB1) >= CONF(AB2)
AND CONF(AB1) >= CONF(AB3)
AND CONF(AB1) >= CONF(AB4)
AND CONF(AB1) >= CONF(AB5)
THEN goal
AND DISPLAY RB1

RULE 280
IF TB
AND CONF(AB2) >= CONF(AB1)
AND CONF(AB2) >= CONF(AB3)
AND CONF(AB2) >= CONF(AB4)
AND CONF(AB2) >= CONF(AB5)
THEN goal
AND DISPLAY RB2

RULE 285
IF TB
AND CONF(AB3) >= CONF(AB1)
AND CONF(AB3) >= CONF(AB2)
AND CONF(AB3) >= CONF(AB4)
AND CONF(AB3) >= CONF(AB5)
THEN goal
AND DISPLAY RB3

RULE 290
IF TB
AND CONF(AB4) >= CONF(AB1)
AND CONF(AB4) >= CONF(AB2)
AND CONF(AB4) >= CONF(AB3)
AND CONF(AB4) >= CONF(AB5)
THEN goal
AND DISPLAY RB4

RULE 291
IF TB
AND CONF(AB5) >= CONF(AB1)
AND CONF(AB5) >= CONF(AB2)
AND CONF(AB5) >= CONF(AB3)
AND CONF(AB5) >= CONF(AB4)
THEN goal
AND DISPLAY RB5

RULE 295
IF TC
AND CONF(AC1) >= CONF(AC2)
AND CONF(AC1) >= CONF(AC3)
AND CONF(AC1) >= CONF(AC4)
AND CONF(AC1) >= CONF(AC5)
AND CONF(AC1) >= CONF(AC6)
THEN goal
AND DISPLAY RC1
```

```
RULE 300
IF TC
AND CONF(AC2) >= CONF(AC1)
AND CONF(AC2) >= CONF(AC3)
AND CONF(AC2) >= CONF(AC4)
AND CONF(AC2) >= CONF(AC5)
AND CONF(AC2) >= CONF(AC6)
THEN goal
AND DISPLAY RC2

RULE 305
IF TC
AND CONF(AC3) >= CONF(AC1)
AND CONF(AC3) >= CONF(AC2)
AND CONF(AC3) >= CONF(AC4)
AND CONF(AC3) >= CONF(AC5)
AND CONF(AC3) >= CONF(AC6)
THEN goal
AND DISPLAY RC3

RULE 310
IF TC
AND CONF(AC4) >= CONF(AC1)
AND CONF(AC4) >= CONF(AC2)
AND CONF(AC4) >= CONF(AC3)
AND CONF(AC4) >= CONF(AC5)
AND CONF(AC4) >= CONF(AC6)
THEN goal
AND DISPLAY RC4

RULE 311
IF TC
AND CONF(AC5) >= CONF(AC1)
AND CONF(AC5) >= CONF(AC2)
AND CONF(AC5) >= CONF(AC3)
AND CONF(AC5) >= CONF(AC4)
AND CONF(AC5) >= CONF(AC6)
THEN goal
AND DISPLAY RC5

RULE 312
IF TC
AND CONF(AC6) >= CONF(AC1)
AND CONF(AC6) >= CONF(AC2)
AND CONF(AC6) >= CONF(AC3)
AND CONF(AC6) >= CONF(AC4)
AND CONF(AC6) >= CONF(AC5)
THEN goal
AND DISPLAY RC6
```

```
RULE 315
IF TD
AND CONF(AD1) >= CONF(AD2)
AND CONF(AD1) >= CONF(AD3)
AND CONF(AD1) >= CONF(AD4)
AND CONF(AD1) >= CONF(AD5)
AND CONF(AD1) >= CONF(AD6)
THEN goal
AND DISPLAY RD1

RULE 320
IF TD
AND CONF(AD2) >= CONF(AD1)
AND CONF(AD2) >= CONF(AD3)
AND CONF(AD2) >= CONF(AD4)
AND CONF(AD2) >= CONF(AD5)
AND CONF(AD2) >= CONF(AD6)
THEN goal
AND DISPLAY RD2

RULE 325
IF TD
AND CONF(AD3) >= CONF(AD1)
AND CONF(AD3) >= CONF(AD2)
AND CONF(AD3) >= CONF(AD4)
AND CONF(AD3) >= CONF(AD5)
AND CONF(AD3) >= CONF(AD6)
THEN goal
AND DISPLAY RD3

RULE 330
IF TD
AND CONF(AD4) >= CONF(AD1)
AND CONF(AD4) >= CONF(AD2)
AND CONF(AD4) >= CONF(AD3)
AND CONF(AD4) >= CONF(AD5)
AND CONF(AD4) >= CONF(AD6)
THEN goal
AND DISPLAY RD4

RULE 335
IF TD
AND CONF(AD5) >= CONF(AD1)
AND CONF(AD5) >= CONF(AD2)
AND CONF(AD5) >= CONF(AD3)
AND CONF(AD5) >= CONF(AD4)
AND CONF(AD5) >= CONF(AD6)
THEN goal
AND DISPLAY RD5
```

```
RULE 340
IF TD
AND CONF(AD6) >= CONF(AD1)
AND CONF(AD6) >= CONF(AD2)
AND CONF(AD6) >= CONF(AD3)
AND CONF(AD6) >= CONF(AD4)
AND CONF(AD6) >= CONF(AD5)
THEN goal
AND DISPLAY RD6
```

DISPLAY XXX

You will now be asked a series of questions to determine the general category of your most probable delay.
Please enter the appropriate value for the confidence interval on EVERY question.

Press the F2 key to begin the questioning.

DISPLAY ONE

From your input, we have determined that the most probable delay will originate from uncontrollable sources.

We will now explore the area of uncontrollable delays to determine a more specific cause.

Press key F2 to continue.

DISPLAY TWO

From your input, we have determined that the most probable delay will originate from the owner.

We will now explore the area of owner caused delays to determine a more specific cause.

Press key F2 to continue.

DISPLAY THREE

From your input, we have determined that the most probable delay will originate from the designer.

We will now explore the area of designer caused delays to determine a more specific cause.
Press key F2 to continue.

DISPLAY FOUR

From your input, we have determined that the most probable delay will originate from the contractor.
We will now explore the area of contractor caused delays to determine a more specific cause.

Press key F2 to continue.

DISPLAY RA1

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be severe weather and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Eliminating severe weather is impossible. Therefore, we must minimize the effects of this delay on the project. In order to accomplish this, you must clearly state in the contract documents who will carry the insurance for monetary losses and provisions should be made for adjustment of project schedule due to severe weather.

DISPLAY RA2

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be severe weather and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Eliminating severe weather is impossible. Therefore, we must minimize the effects of this delay on the project. In order to accomplish this, you must clearly state in the contract documents who will carry the insurance for monetary losses and contractual provisions must be made for adjustment of project schedule due to severe weather.

DISPLAY RA3

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be unreliable subcontractors and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Within the contract documents, assign the general contractor all responsiblity for subcontractor failure or poor performance.

DISPLAY RA4

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be lack of material availability and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

If possible, eliminate the material in question from design and substitute an easily available material. If not, push the general contractor or subcontractors to find new sources for the unavailable material. Contract should provide sufficient time for contractor to obtain the material.

DISPLAY RA5

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be labor unrest or strikes and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Specify in the contract documents that if the strike is beyond the control of the contractor, that each party will absorb their own losses due to the strike, and a provision for an equitable time adjustment should be included in the contract. If not, the contract should include provisions for the owner to hire a non-union contractor to complete the work at the expense of the original contractor.

DISPLAY RA6

Based on your confidence level input within the area of uncontrollable delay, we have determined the most probable specific cause of delay to be local opposition to the project and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Local opposition to the project is clearly the owners responsibility and the owner must seek avenues to appease the local population. Contract provisions should clearly state that the owner will be completely responsible for any delay caused by local opposition to the project. This will prevent the contractor from including in his bid a contingency to cover this possible delay.

DISPLAY RB1

Based on your confidence level input within the area of owner caused delay, we have determined the most probable specific cause of delay to be the owners questionable borrowing capacity and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

You should ensure that a loan has been secured that can adequately pay all contract fees, including progress

payments, developer fees, etc. Also, the loan must be of duration and interest rate so that all payments are affordable.

DISPLAY RB2

Based on your confidence level input within the area of owner caused delay, we have determined the most probable specific cause of delay to be the small size or the youthfulness of the owner's company and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Make sure the market is going to remain strong for your product(s) for a duration which will make the construction project economically advantageous.

DISPLAY RB3

Based on your confidence level input within the area of owner caused delay, we have determined the most probable specific cause of delay to be direct owner involvement in construction and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Allow the contractor and developer the full responsibility for which their firms are held liable. Allow the developer to act as the owners representative on most items directly involving construction progress and payments. Also, minimize unnecessary owner requested change orders which are trivial and simply delay construction.

DISPLAY RB4

Based on your confidence level input within the area of owner caused delay, we have determined the most probable specific cause of delay to be late progress payments and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Due to contractors financial responsiblities, progress payments must be made consistently to avoid construction delays and costly litigation.

DISPLAY RB5

Based on your confidence level input within the area of owner caused delay, we have determined the most probable specific cause of delay to be the risky nature of the project and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Evaluate possible financial gain of successful project verses possible economic losses due to project failure. Transfer risk to the parties which have the most control over the it.

DISPLAY RC1

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be designer inexperience and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the designer to make sure he has adequate experience for this type of design.

DISPLAY RC2

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be experimental construction techniques and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Try to minimize or eliminate any unique construction techniques if economically feasible. Also, must allow adequate time for designer to review all aspects of the experimental construction techniques in detail.

DISPLAY RC3

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be fast track operation of project and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Minimize the amount of fast track requests for proposals by having drawings as complete as possible when construction begins. Also, make sure a good relationship exists between all design-build team members so that fast track operation goes smoothly. A complete turn-key operation from the start might eliminate some typical fast-track problems.

DISPLAY RC4

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be slow approval of shop drawings

and submittals and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify designer and minimize the amount of changes in the drawings and specs since these will require additional review by the designer.

DISPLAY RC5

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be designer's work load is too large and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify designer and perform a thorough study of his current job volume and size of staff to assure he can commit the time and effort required for his responsiblilties on the project.

DISPLAY RC6

Based on your confidence level input within the area of designer caused delay, we have determined the most probable specific cause of delay to be designer's unfamiliarity with local building codes and environmental regulations and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the designer and have you or the general contractor provide him with all the available information on the subject.

DISPLAY RD1

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable specific cause of delay to be the contractor's inexperience and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the contractor through past job volume, past job types, bonding capacity, size, reputation, etc.

DISPLAY RD2

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable

specific cause of delay to be insufficient financing or bonding capacity and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the contractor through past job volume, past job types, bonding capacity, size, reputation, etc. Also, check his credit source directly for his complete financial capacity.

DISPLAY RD3

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable specific cause of delay to be poor contractor management techniques and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the contractor through past job volume, past job types, bonding capacity, size, reputation, etc. Also, it is possible to hire the services of a construction management consultant to monitor and assist the general contractor.

DISPLAY RD4

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable specific cause of to be insufficient manpower to supervise and coordinate the project delay and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the contractor through past job volume, past job types, bonding capacity, size, reputation, etc. Also, thoroughly examine his current job volume and work capacity.

DISPLAY RD5

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable specific cause of delay to be significant discrepency in contractor's bid and owner's estimate and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Carefully review, line by line, your own job estimate and request the contractor to do the same. If allowable, get the contractors estimating documents to check for errors or omissions.

DISPLAY RD6

Based on your confidence level input within the area of contractor caused delay, we have determined the most probable specific cause of delay to be contractors poor record of safety, quality, and untimely completion of previous projects and recommend the following actions to minimize or eliminate this source.

RECOMMENDATIONS:

Prequalify the contractor through past job volume, past job types, bonding capacity, size, reputation, etc.

EXPAND WEATHER

If you are in an area and/or season which is susceptible to tornadoes, hurricanes, floods, high winds, or fires this could severely impact the schedules of the project. Not only because lost construction days, but also because of repair and replacement type of work.

EXPAND POLITICAL

If the project is unpopular with local residents, conservation groups, or environmental organizations, the project could be severely delayed due to legal red-tape or protests. Also, the political, economic, and social states of the local government or people must be considered since war, embargoes, and/or civil unrest could severely delay or terminate the project.

EXPAND LABOR

Although it may be difficult or impossible to predict strikes, a general industry trend or shortage of quality labor can usually be foreseen.

EXPAND MATERIAL

If the project requires material that must be either specially manufactured, is limited in availability, or must be shipped from distant locations, the probability of delay exists.

EXPAND FINANCIAL

If your economic situation is rather tense due to past financial obligations or difficulties in acquiring revenues, the project may strain your financial capabilities and cause legal delays due to non-payment.

EXPAND BORROWING CAPACITY

If your economic situation is rather tense due to past financial obligations or difficulties in acquiring revenues,

the project may strain your financial capabilities and cause legal delays due to non-payment.

EXPAND PROJECT NEED

If your present office or industrial resources can adequately handle the needs of your company, the added revenues of this project might not be worth the finacial committment of the construction. Also, if the project is speculative in nature, the need may not exist for the structure in the near future and construction could be terminated with the corresponding loss of capital.

EXPAND OWNER INVOLVEMENT

If you feel a need to become directly involved in the construction process or feel that you will be instigating

many change orders, this will cause a delay in project completion.

EXPAND EXPERIENCE

Designers that are inexperienced or new to the business, typically make omissions or mistakes in design documents which will require correction and may cause delay.

EXPAND CAPACITY

If the designer's current work load is consuming his design resources, he may not have the time or ability to adequately handle your project in the manner he should.

EXPAND FAST TRACK

If the documentation for the job is incomplete, or the job is not bought out, when construction begins, it will be difficult for the designer and contractor to bring the project in under a targeted cost.

EXPAND COMPLEX

If the design is unique or unusual, the designer will need more time to complete the documents and there's a greater possiblity of design errors, omissions, and corrections.

EXPAND HISTORY

If the contractor is inexperienced or new to this type or size of construction, there is a definite possiblity that his difficulties will delay the construction process.

EXPAND FINANCIAL STABILITY

If the contractor's credit or bonding capacity is in question, there is a good possiblity that he will default the

job during construction. Having the bonding company finish the job will cause delay.

EXPAND SIZE and CAPACITY

This is self-explanitory, please re-examine question or statement.

EXPAND MANAGEMENT

The contractor's track history in these areas is a good device to predict future problems and delay in the same areas.

EXPAND AA1

If you are in an area and/or season which is susceptible to tornadoes, hurricanes, floods, high winds, or fires this could severely impact the schedules of the project. Not only because lost construction days, but also because of repair and replacement type of work

EXPAND AA2

If you are in an area and/or season which is susceptible to tornadoes, hurricanes, floods, high winds, or fires this could severely impact the schedules of the project. Not only because lost construction days, but also because of repair and replacement type of work

EXPAND AA3

The failure or slow progress of key subcontractors can delay the entire constuction process.

EXPAND AA4

If the project requires material that must be either specially manufactured, is limited in availability, or must be shipped from distant locations, the probability of delay exists.

EXPAND AA5

Although it may be difficult or impossible to predict strikes, a general industry trend or shortage of quality labor can usually be foreseen and should be accounted for.

EXPAND AA6

If the project is unpopular with local residents, conservation groups, or environmental organizations, the project could be severely delayed due to legal red-tape or protests. Also, the political, economic, and social states of the local government or people must be considered since war,

embargoes, and/or civil unrest could severely delay or terminate the project.

EXPAND AB1

If your economic situation is rather tense due to past financial obligations or difficulties in acquiring revenues, the project may strain your financial capabilities and cause project shutdown due to non-payment.

EXPAND AB2

If you are feel this project would be a major financial risk and could possibly result in the failure of the company, intermediate payments could be delayed which in turn would delay contractors progress.

EXPAND AB3

If you feel a need to become directly involved in the construction process or feel that you will be instigating many change orders, this will cause a delay in project completion.

EXPAND AB4

If in the past, you have had late progress payments on a similar project, the same events could result in late progress payments on this job and a corresponding delay.

EXPAND AB5

If the economic success of the project depends on factors such as future market trends in your product then the downturn of this market could cause the project to be no longer necessary. If construction has already started it will be very costly to terminate the project.

EXPAND AC1

Designers that are inexperienced or new to the business, typically make omissions or mistakes in design documents which will require correction and may cause delay.

EXPAND AC2

If the design is unique or unusual, the designer will need more time to complete the documents and there's a greater possiblity of design errors, omissions, and corrections. Also the contractor could have difficulty in building these new construction elements.

EXPAND AC3

If the documentation for the job is incomplete, or the job is not bought out, when construction begins, it will be

difficult for the designer and contractor to bring the project in under a targeted cost.

EXPAND AC4

This is self-explanitory, please re-examine question or statement.

EXPAND AC5

If the designer's current work load is consuming his design resources, he may not have the time or ability to adequately handle your project in the manner he should.

EXPAND AC6

If the designer is located outside the municipality where construction will occur, he probably will not be familiar with local building codes and zoning regulations which may lead to delays.

EXPAND AD1

If the contractor is inexperienced or new to this type or size of construction, there is a definite possiblity that his difficulties will delay the construction process.

EXPAND AD2

If the contractor's credit or bonding capacity is in question, there is a good possiblity that he will default the job during construction. Having the bonding company finish the job will cause delay.

EXPAND AD3

If the company refuses to use modern computers, techniques, or construction methods, his productivity will be lower than most constractors and result in longer construction durations.

EXPAND AD4

Although the contractor may bid and accept the job, his staff may be already consumed with ongoing projects. This lack of manpower will lead to quality and safety problems requiring rework and delay the completion of the project.

EXPAND AD5

If the contractor has made mistakes in his bid, he will be reluctant to complete the job without receiving additional compensation. Undoubtedly, a dispute will arise and will probably delay the project completion.

EXPAND AD6

This is self-explanitory, please re-examine question or statement.

TEXT A
examine one particular area of delay.

TEXT B
have the program determine the most likely cause of delay for your project.

TEXT Q
Select from the following causes of delay the one you desire to explore.

TEXT UNC
uncontrollable delays.

TEXT OWN
owner caused delays.

TEXT AE
designer caused delays.

TEXT CONTRACTOR
contractor caused delays.

TEXT WEATHER
There is a high probability of severe weather or natural disaster occurring.

TEXT POLITICAL
This project is politically sensitive.

TEXT LABOR
Labor forces available for the project will be limited due to either the possibility of a labor strike or future resource criticality.

TEXT MATERIAL
This project requires specially manufactured material or materials for which the supply is limited.

TEXT FINANCIAL
You are not financially stable.

TEXT BORROWING CAPACITY
Your borrowing capacity is limited.

TEXT PROJECT NEED
The need for the project is questionable and project may be terminated prior to completion.

TEXT OWNER INVOLVEMENT
You will be highly involved in project operations and are

likely to institute many change orders.

TEXT EXPERIENCE
The designer is relatively new or is not experienced in this type of construction.

TEXT CAPACITY
The current workload for the designer exceeds the workload capacity of the firm.

TEXT FAST TRACK
The designer has been forced to complete the plans and specifications in a shorter time frame than normally required or construction has started before the plans and specifications are 100 percent complete.

TEXT COMPLEX
The design is extremely complex or unique.

TEXT HISTORY
The contractor is not experienced in this type of construction.

TEXT FINANCIAL STABILITY
The contractor is not financially stable.

TEXT SIZE and CAPACITY
The contractor is not large enough to handle the project or has too large of a workload to perform all contracts satisfactorily.

TEXT MANAGEMENT
The companys' management utilizes outdated management techniques or company has history of late completions, poor quality, or poor safety record.

TEXT AA1
The geographic location has a high probability of severe weather, i.e., tornadoes, hurricanes, floods, high winds, etc..

TEXT AA2
Normal weather conditions are poor for construction in this area.

TEXT AA3
Subcontractors on this job are unreliable.

TEXT AA4
There is a good possiblity of shortage of materials.

TEXT AA5
There is local labor unrest, a short supply of skilled workers or union contract expires during job duration.

TEXT AA6
There is likelihood of local opposition to the project.

TEXT AB1
Your borrowing capacity is in question.

TEXT AB2
You are a new or relatively small organization.

TEXT AB3
You typically become involved in daily construction operations or frequently change items in the plans and specifications after contract award.

TEXT AB4
You historically make late progress payments.

TEXT AB5
The project is very risky or dependent on agencies outside the design/development team.

TEXT AC1
The designer is not experienced in this type of construction.

TEXT AC2
The project involves experimental construction techniques.

TEXT AC3
Construction started prior to 100% completion of drawing and specifications.

TEXT AC4
The designer is slow in approving shop drawings and submittals.

TEXT AC5
The designer's staff is small or current job volume is very large.

TEXT AC6
The designer is not familiar with local building codes or environmental regulations.

TEXT AD1
The contractor is not experiences in this type of construction.

TEXT AD2
The contractor does not have sufficient borrowing or bonding capacity.

TEXT AD3
The contractor does not use modern management techniques.

TEXT AD4
The contractor does not have sufficient manpower to coordinate or supervise the project.

TEXT AD5
The contractor's bid was significantly lower than your estimate.

TEXT AD6
Other projects completed by this contractor have poor records of safety, quality, or timely completion.

TEXT AA11
(1) The geographic location has a high probablility of severe weather, i.e., tornadoes, hurricanes, floods, high winds, etc..

TEXT AA21
(2) Normal weather conditions are poor for construcion in this area.

TEXT AA31
(3) Subcontractors on this job are unreliable.

TEXT AA41
(4) There is a good possiblity of shortage of materials.

TEXT AA51
(5) There is local labor unrest, a short supply of skilled workers or union contract expires during job duration.

TEXT AA61
(6) There is likelihood of local opposition to the project.

TEXT AB11
(1) Your borrowing capacity is in question.

TEXT AB21
(2) You are a new or relatively small organization.

TEXT AB31
(3) You typically become involved in daily construction operations or frequently change items in the plans and specifications after contract award.

TEXT AB41
(4) You historically make late progress payments.

TEXT AB51
(5) The project is very risky or dependent on agencies outside the design/development team.

TEXT AC11
(1) The designer is not experienced in this type of construction.

TEXT AC21
(2) The project involves experimental construction techniques.

TEXT AC31
(3) Construction started prior to 100% completion of drawing and specifications.

TEXT AC41
(4) The designer is slow in approving shop drawings and submittals.

TEXT AC51
(5) The designer's staff is small or current job volume is very large.

TEXT AC61
(6) The designer is not familiar with local building codes or environmental regulations.

TEXT AD11
(1) The contractor is not experiences in this type of construction.

TEXT AD21
(2) The contractor does not have sufficient borrowing or bonding capacity.

TEXT AD31
(3) The contractor does not use modern management techniques.

TEXT AD41
(4) The contractor does not have sufficient manpower to coordinate or supervise the project.

TEXT AD51
(5) The contractor's bid was significantly lower than your estimate.

TEXT AD61
(6) Other projects completed by this contractor have poor records of safety, quality, or timely completion.

TEXT M
You have selected the area of UNCONTROLLABLE DELAY. Select from the following list the cause of delay you wish to examine.

TEXT N
You have selected the area of OWNER CAUSED DELAY. Select from the following list the cause of delay you wish to examine.

TEXT O
You have selected the area of DESIGNER CAUSED DELAY. Select

from the following list the cause of delay you wish to examine.

TEXT P
You have selected the area of CONTRACTOR CAUSED DELAY.
Select from the following list the cause of delay you wish to examine.

END

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CONSTRUCTION SCHEDULE

THE GEORGE HYMAN CONSTRUCTION CO.

APPENDIX II

Excerpt from Construction Claims [Rubin et al,83]

CASE HISTORY

The following hypothetical situation is an extended case history showing how a tangle of overlapping delays can be analyzed. It was originally a chapter that appeared in *Construction Contracts*, published by the Practising Law Institute. It is reprinted here with their permission. While this section is addressed to attorneys, it is not technical, and the analysis and examples are useful to all parties in the construction process.

In this chapter we will deal with how to analyze construction delays. We will consider only the interval of time from the moment the client enters the attorney's office until the claim is prepared for submission to the owner or the complaint is drawn.

The client tells the following story: he had a $700,000, thirteen-month contract to construct a five-story, steel-frame office building. Completion was delayed five months; he lost $250,000 and, to add insult to injury, the owner assessed him $9,000 liquidated damages ($100 per day for three months) plus actual damages of $10,000 representing loss of rentals in the building.

The client lost two months as a result of a change in design from closed-end pipe piles to large diameter step-taper piles. One month was lost due to the architect's delay in approving shop drawings; two months due to a roofing workers' strike and one month as a result of working during the wintertime. The owner ordered the client to accelerate the interior finishing work by working nights and weekends, enabling him to make up one month's delay.

The client wants to know whether he has a case. How much can he collect from the owner and does he have to pay any liquidated damages?

What does the attorney do to answer the client's questions? Several steps should be followed. The first step is to assemble the mass of papers that have survived the construction of the project. (An enumeration of. records is omitted; these include, for example, daily reports, payment requisitions, progress schedules, and so forth.)

The second step in analyzing the client's problem is to understand the job thoroughly. The attorney should barrage the client with questions about how the job was actually constructed. He should ask to see the plans, have them explained to him and examine all the available photographs of the job. The attorney should continue to ask the client questions about the job until satisfied that he understands it thoroughly

The third step in analyzing the client's problems is to read the contract documents, particularly the agreement and general conditions. Usually, a completion date is specified, or a period of completion in consecutive calendar days from the date of a notice-to-proceed from the owner. The contract usually states that time is of the essence. There is often a contract clause that sets forth liquidated damages for each day's delay in completion. There is often a clause setting forth justifiable causes for which the owner will give an extension of contract time. This clause is often coupled with a clause which states that an extension of contract time is the contractor's sole remedy for delay and that in no event will the owner be liable for damages. The legal effect of such a provision will be discussed later.

PREPARING CHARTS AND GRAPHS

The next step in evaluating a client's delay problems is to organize and assemble the facts presented. A most expeditious way is to prepare a number of charts and graphs.

Chart #1—Bar Chart—Intended Schedule

Bar Chart #1 shows the contractor's intended schedule for performing the work. This is known as a bar chart, which divides the work into its major elements or activities.

Chart #1 is greatly simplified. It divides the work into only five major activities: the foundation, structural steel, masonry, roof, and interior work. Adjacent to each activity is a bar representing the intended starting date, the duration, and the intended completion date. Ordinarily, in practice, a bar chart for a project of the scope set forth in the hypothetical example (i.e., a $700,000 five-story, steel-frame office building) would contain anywhere between 20 and 40 separate activities. The problem or weakness with a simple bar chart is that it does not show the interrelationship of the various activities nor the logic behind the contractor's intended performance nor the percentage of completion at any given time.

Chart #2—CPM Progress Schedule—Intended Schedule

From such a simple bar chart one is not able to ascertain which activities are independent of others and which activities are dependent for their start or completion upon the start or completion of other items. This information can best be represented on another type of progress chart, known as a CPM (Critical Path Method) schedule. Chart #2 shows the same construction activities as Chart #1, but laid out in somewhat different manner. Each activity has the same duration; however, the interdependence of the activities is shown. For example, the structural steel is shown to start only upon the completion of the foundation work. Then the chart splits into two segments. The masonry work can be performed at the same time as the roofing work. However, the masonry work takes three months to perform whereas the roofing work takes only two months. It is then shown that the interior finishing work cannot proceed until

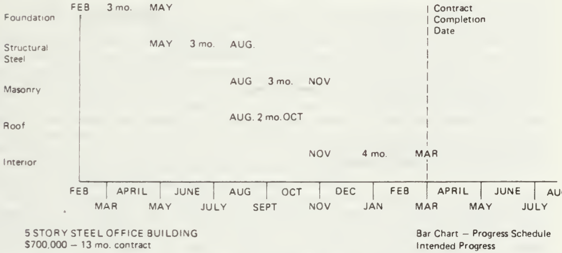

Chart #1.

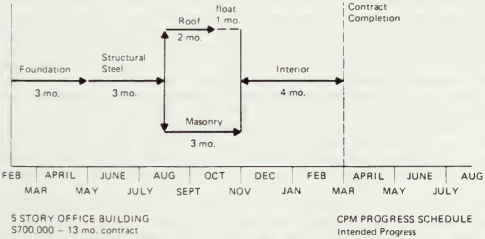

Chart #2.

the completion of both the roof and the masonry work. The one month excess time on the path of the roofing work is known as "float time." This means that although the roofing work is shown to start at the same time as the masonry work, in fact, the roofing work could start one month later without and delay in the completion of the entire project.

The ⟶ line represents the critical path through the project which, by definition, means that the prolongation of any single activity along the critical path will prolong the completion of the entire project. The roofing work is not on the critical path because of the one month of "float time."

Chart #3—Bar Chart—Actual Progress

The following chart requires a meeting with the client and use of his records. Chart #3 is prepared and superimposed upon Chart #1 indicating the periods when the various construction activities were actually performed. This information is often obtainable from the contractor's progress payment requisitions, which indicate the percentage of work completed for each such activity during each month of the job. Information regarding the dates of actual performance can also be obtained from the foreman's time card, the superintendent's daily reports, the correspondence, the job meeting minutes, and the photographs.

An explanation is then requested from the client for each delay, prolongation of work, or change in sequence of the work. For example, we see on Chart #3, that although the foundation work was scheduled to begin February 1, it did not commence until March 1. The client then recalls that there was a strike at the outset of the job which prevented the start of foundation work for one month. Then we see that the foundation work proceeded for one month during March and then was suspended for one month in April. The client says that this suspension was ordered by the owner after it became apparent that the specified closed-end pipe piles were being driven much deeper than anticipated. The architect took one month to conduct these tests to redesign the work. We then see that the work was resumed in May and proceeded three months until completion in August. This indicates that the aggregate time for performance of the foundation work was four months rather than the three months intended. Your client explains that the driving of the large diameter step-taper piles proceeded more slowly than the closed-end pipe piles as a result of the different pile driving equipment required to be used.

We then see that the structural steel work did not begin until September, one month after the completion of the foundation work, although it was originally scheduled to have begun immediately upon completion of the foundation work. The client explains that while he submitted structural steel shop drawings at the time required, the owner's architect unreasonably delayed approving them, thereby preventing the start of the structural steel work until September. We see that the structural steel work was performed in a duration of three months, as it was originally scheduled to be performed.

We next see that upon completion of the structural steel work, the masonry work commenced immediately, but had a duration of four months rather than the three months originally scheduled. Your client explains that the additional month of performance time was caused by the work being pushed into the winter months. Originally, the masonry work was to be performed from August to November, during good weather. However, it actually had to be performed in the middle of the winter which resulted in one month's lost time. We next see that the roofing work, while originally scheduled to begin at the same time as the masonry work, did not begin until one month later. Your client explains that, as originally scheduled, there was one month of float time, which he decided to take advantage of because he knew that the masonry work would be prolonged during the winter. However, after proceeding for a month, the roofing work was suspended for two months during February and March. Your client explains that there was an industry-wide roofers' strike, which prevented the performance of any work during this period. Thereafter, we see that the roofing work took two months to complete from April to June, a total performance time of three months, whereas only two months was originally scheduled. Your client explains that defects were found in the roofing work by the architect which took your client approximately one month to repair.

You then see that the interior work started in May and was completed in a duration of three months rather than the four months scheduled. Your client explains that in May the owner demanded that your client accelerate performance by working evenings and weekends in order to complete the project as quickly as possible and that one month's time was made up by performing the work in this manner.

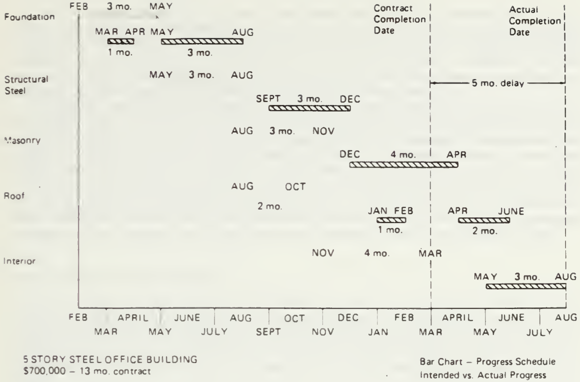

Chart #3.

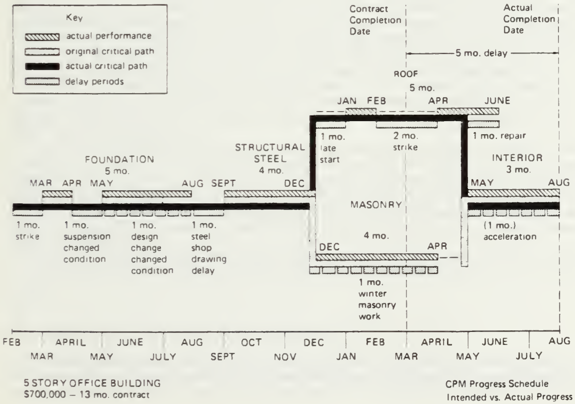

Chart #4.

Chart #4—CPM Progress Schedule—Actual Progress

Your next step in analyzing your client's claim requires you to insist that he prove each and every delay to you from the available records rather than rely upon his memory. Some clients have a tendency to accentuate the positive and eliminate the negative. Time dulls memories, especially unpleasant memories. As noted previously, it is apparent that your client has forgotten or neglected to tell you several relevant facts regarding the case, such as the initial one-month delay caused by the strike. Now you must use the records in order to test the validity of each of his contentions.

This is best done with the aid of another form of CPM progress schedule. Actual progress is laid out in a line, in much the same format as was the original CPM schedule. The original critical path and critical path activity duration, is indicated by the line. The line represents the actual critical path through the job. It is significant to note that whereas, as originally scheduled, the critical path went through the masonry work, now the critical path shifts and goes through the path of the roofing work It is also noted that the critical path is not through the entire roofing work, but only a portion of it. The line and the line represents delays. A line represents a total suspension of work. A line represents a delay that occurs over an interval of time. For example, the one-month prolongation of the masonry work occurred during the four-month interval from December to April.

Using Records to Verify Delays

In reviewing your client's records you find that the one-month intial strike is substantiated. You next find that, in fact, the architect did order a one-month suspension in the foundation work and that the foundation work did, in fact, take one month longer to perform using the different equipment required for the step-tapered piles. This is ascertained by comparing the production records of the closed-end pipe piles for the month of March, prior to the suspension, with the pile driving records from May through August.

You then find that the one-month steel shop drawings delay is not properly attributable to the owner, but, rather, was your client's fault, albeit unbeknownst to him. You find that your client's steel erection subcontractor did, in fact, submit shop drawings on time. These were promptly reviewed by the architect and returned to the subcontractor for correction because they contained substantial errors. The subcontractor then delayed in correcting the errors and the architect finally approved the revised shop drawings promptly after resubmission to him. This information is ascertained both from an examination of the shop drawing log maintained by your client and a close examination of the shop drawings themselves.

Frequently, architects use the vehicle of shop drawings to effect substantial design changes. It is therefore necessary to examine carefully each comment and correction made by the architect on the shop drawings to determine whether he is merely correcting errors made by the contractor or whether he is, in effect, redesigning the work.

You then see that the one-month delay in starting the roofing work was simply a matter of your client's exercise of choice not to commence the roofing work until that time. However, he did not know that there would be a roofers' strike which, in fact, delayed the roofing work for two months. Thereafter it took two months to complete the roofing work, of which, one month was due to repairs required by the architect because of defects in the workmanship—the fault of the client. However, it is noted that the repair of the defects did not prevent the interior finishing work from commencing, i.e., the repairs did not fall on the critical path.

Your client's records indicate that in fact he did work overtime and weekends and that the one month shortening of the intended four-month interval for interior work was directly attributable to that overtime work

Deciding on Excusability and Compensability

Consider whether each of the delays was excusable or nonexcusable and, if excusable, whether it was compensable or noncompensable The one-month initial strike is excusable but noncompensable. The one-month suspension due to a redesign of the foundation is both excusable and compensable. The one-

month prolongation of the foundation work directly attributable to the change in design would also be both excusable and compensable.

Change Orders

Here, however, it is important to note that your client's records must be examined carefully to find out whether he waived any further rights to compensation on account of the change in design. Frequently, in granting change orders, an owner requires the contractor to waive any further costs attributable to the work encompassed by the change order and specifies a total extension of time that will be allowed for the change. Since the ultimate effect on final completion of the entire job often cannot be determined at the time the changed work is being performed, it is advisable for contractors to execute change orders with a reservation clause. This clause should state that the change order is for the direct cost of the changed work, and, and does not include any impact costs or extension of contract time, which are specifically reserved until such time as they can be finally ascertained.

The one-month steel shop drawing delay is nonexcusable.

Analyzing Concurrent Delay Effects

Now you come to the split paths of masonry/roofing work. These include concurrent delays and the analysis is a rather complicated one.

Start with the masonry path. The one-month prolongation of the masonry work as a result of the necessity of performance in the winter would ordinarily be inexcusable, since, in our case, the winter was an ordinary one, not an unusually severe one. However, in our case, there were three preceding months of excusable delay. If your client had started masonry work three months earlier, in September, it would have been completed prior to the onset of winter. Therefore, the masonry delay, considered alone, ought to be excusable. There were, however, only two months of precedent compensable delay. (See the earlier discussion concerning when delay is excusable, compensable, nonexcusable or noncompensable.) If he had started the masonry work two months earlier, in October, the work would have been performed in two months of good weather and one month, December, of winter weather. In such event the masonry would undoubtedly have been prolonged for a period less than the one month it was actually prolonged. Therefore, considered alone, before analysis of the concurrent roof delays, there would be somewhat less than one month of compensable delay for the masonry work, even though the entire one month delay is excusable.

Next, we consider the delays in the roofing work. The initial one-month late start of the roofing work by your client's choice raises the issue: Who owns the float time? While this has not been raised in many cases, the prevailing view is that the contractor owns the float time. The two-month delay in the roofing work, therefore, ought to be excusable. However, if there was precedent inexcusable delay attributable to your client, pushing him into the strike, the strike ought then to be inexcusable. In the same way, if there was precedent compensable delay which pushed the contractor into the roofing strike period, the time of duration of the roofing strike ought to be both excusable and compensable. Here we find that there were three months of precedent excusable delay. Had the roofing work been started three months earlier, the strike would have been avoided. Here, also, we find that there were two months of precedent compensable delay. Had the roofing work been started two months earlier, it would have been completed before the roofing strike. Therefore the roofing strike delay should be both excusable and compensable, when considered in the absence of the concurrent masonry delay.

In considering the masonry path and the roofing path, we find that there was an aggregate delay of two months along these paths. There were two months of excusable delay in the roofing path and one month of excusable delay in the masonry path, with the remaining month in the masonry path being float time. The net result should thus be two months of excusable delay.

In the masonry path, there was somewhat less than one month of compensable delay and there were two months of compensable delay in the roofing path. Therefore, the aggregate of these concurrent delays would be something less than one month of compensable delay. (See above discussion of concurrent delays.)

DETERMINING RESPONSIBILITY FOR DELAY DAMAGES

Now you are in a position to answer the questions posed by your client. Was the order to accelerate a valid one? Yes. As of May, when the order was given, there was a six-month delay, only five of which were excusable. Therefore, the owner was entitled to demand that your client make up the one-month of nonexcusable delay by accelerating performance.

If the order were not a proper one, the owner would be liable in damages for the overtime wages paid your client's employees plus the loss of productivity attributable to the increased number of hours per day and the increased number of days per week that the employees worked. Studies have shown that men working under these conditions are less productive than when working a normal week.

May Contractor Recover Damages From Owner?

Is your client entitled to recover any damages from the owner? In spite of the contract clause stating that the contractor's sole remedy is an extension of contract time, it has been held in New York and elsewhere that such a clause is not enforceable and that an owner will be liable in damages for the unreasonable delays he causes. The delay resulting from the change in foundation design aggregated something less than four months—two months while the foundation work was being performed and then some period less than two months during the concurrent performance of the masonry and roofing work. Your client is entitled to recover mobilization and demobilization costs and equipment standby rental values attributable to the one-month suspension while the architect redesigned the work. He is entitled to labor and material escalation costs attributable to the prolongation of the work.

He is entitled to recover the loss of productivity, aggregating something less than one month's delay, during the masonry work. This is best computed by comparing actual records of masonry work performed in early December, before the winter conditions set in, with the work performed during the winter conditions. If this is not possible, other methods which may be used include a comparison of the actual cost of the masonry work with the reasonably estimated cost of the work, or the application of productivity reduction factors from studies that have been conducted in the industry. The client is also entitled to recover any additional costs of winter protection of the masonry work.

The client is entitled to be compensated for the extended period costs of something less than four months. This would include extended superintendence and supervision, trucking, vehicles and equipment, insurance, miscellaneous field expenses such as telephone, light, shanty, and an allocable proportion of central office overhead for the extended period.

Assessing Liquidated Damages

The next question is whether the owner was entitled to assess liquidated damages for three months. No liquidated damages were properly assessable because the aggregated delay was five months and there were five months of excusable delay.

In the absence of excusable delay, liquidated damages will generally be enforced, as the owner's sole remedy, if they are found to be "reasonable and not a penalty." The sum specified as liquidated damages must be found to be reasonably related to the damages the owner might expect to incur as of the date that he entered into the contract. In the event that the liquidated damages are deemed to be a penalty, the owner may only collect the actual damages he can prove.

The owner is not entitled, in most jurisdictions, to collect both liquidated damages and actual damages. Therefore, if the nature of the project is such that the owner's damage could be easily computed, it would probably be better for an owner not to include a liquidated damages clause. Excluding the clause would permit the owner to collect all of his actual damage in the event of inexcusable delay in completion. If, however, delay damage is not easily computable, such as damage that would occur to a school district from delayed completion of a school, or damage that would accrue to a congregation from delay in completion of a church, it would be advisable to insert reasonable liquidated damages into a construction contract.

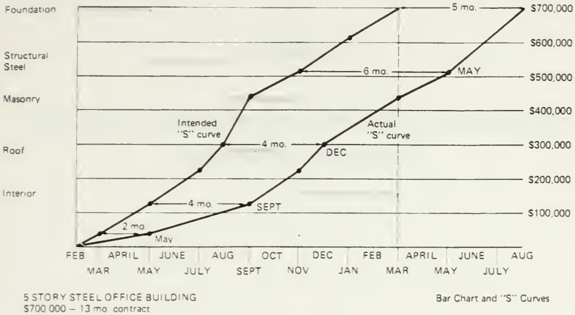

Chart #5.

Chart #5—Bar Chart With "S" Curve

As you can see, even with the use of an oversimplified example, the CPM method of analysis can get quite complicated. In the example chosen, the analysis of the concurrent roof and masonry delay, in light of precedent delays, was exceptionally complicated. One can imagine that if some 50 different activities had to be charted, rather than five, each with different periods and causes of delay, a CPM analysis could become impracticable. Therefore, another method of analysis is often used. This is represented by Chart #5 and includes the super-imposition of an "S" curve over the contractor's intended bar-chart schedule, Chart #1. It should be noted that on the right-hand side of Chart #5 the contract price is plotted in intervals of $100,000. It is possible to compute the amount of money that would be earned per month if the job had proceeded on schedule (from the intended bar chart and the trade payment breakdown). This is represented by the line at the left hand side of Chart #5 labeled Intended "S" Curve. One might think that this ought to be a straight line. However, experience has proven that construction projects often begin somewhat slowly, pick up their rate of progress during the middle of the job, and then tail off towards the end. Thus, the resulting curve is in the shape of an "S." The actual payments made to the contractor each month can be plotted against this curve. Care should be taken however, to exclude change order work from the payments, so that the comparison is valid. Then, at any point along the actual "S" curve, the horizontal distance between the actual curve and the intended curve will indicate the duration that the job is behind schedule at that date.

Chart #5 indicates that, as of May, the job was behind schedule two months; in May, at the time of the owner's order to accelerate the work, the job was six months behind schedule, confirming our prior CPM analysis. "S" curves are helpful in ascertaining whether the job is behind schedule for purposes of termination of contract and orders to accelerate the work. They are also helpful to explain delays in a simplified manner when a CPM analysis is not practicable.

CONCLUSION

There are several conclusions that can be drawn from our discussion. First, the importance of using actual records to analyze delays cannot be overemphasized.

Second, the validity of a CPM analysis is entirely depedent upon the validity of the assumptions made. It is like a deck of cards. If one assumption is proved incorrect, then the entire analysis may collapse. For example, in our hypothetical case, if, in fact, the interior work could be started independent of the completion of the roofing work, the entire analysis and result would be changed. It is important, therefore, in most substantial cases, to retain an outside expert consultant to evaluate the assumptions of the critical path logic to ascertain whether or not they are correct.

APPENDIX III

CPM schedule which includes the impact of delay on the compressed actvities prior to acceleration.

APPENDIX IV

CPM schedule subsequent to the negotiated acceleration.

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